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The Effect of flexographic printing on the compression strength of corrugated shipping containers

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THE EFFECT OF FLEXOGRAPHIC PRINTING ON THE COMPRESSION STRENGTH OF CORRUGATED SHIPPING CONTAINERS

By

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ABSTRACT

THE EFFECT OF FLEXOGRAPHIC PRINTING ON THE COMPRESSION STRENGTH OF CORRUGATED SHIPPING CONTAINERS

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This study examined the effect of flexographic printing, using both natural rubber and photopolymer printing plates, on the top-to-bottom compression strength of RSC style shipping containers. Six sets of factors were studied including, 1) Print location on panels (center, one-inch to edge); 2) Number of panels printed (two majors, all four); 3) Print coverage (15%, 30%); 4) Number of colors of print (one-, two-color); 5) Flute size (B, C); and 6) Shape of print (square, rectangle).

Individual sets of printing plates were produced to represent each factor studied. The containers were manufactured during an "on-line" production run under standard operating conditions. Preconditioning, conditioning, and compression testing was completed based on ASTM standards. The Taguchi Method of statistical design was used to analyze the data.

The results showed that some printing factors significantly affected the compression strength of an RSC style container and should be incorporated into the evaluation of container design.

DEDICATION

This thesis is dedicated in loving memory of my father, Frank R. Eyre. Also to my wife, Susan O. Eyre, our children Michael, Patrick and Megan, and my mother, Ingeborg R. Eyre for all their support and sacrifices.

This thesis is dedicated to my parents, Gerald R. Kaczor and Joyce M. Kaczor. Their love, support, and encouragement made this, and all my accomplishments possible.

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We also wish to thank Professor Anne Barker (RIT College of Engineering, Department of Statistics) for her consultation and assistance on the Taguchi Method of design and the statistical analysis.

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Mobil Chemical Company, Plastic Packaging Division, Pittsford, NY for providing testing materials and resources.

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Mohawk Containers, New Hartford, New York for providing us with production line time and the corrugated containers. Specifically, Michael J. Street of JSC/CCA who coordinated the actual production.

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Finally, we wish to thank all the unnamed operators who helped throughout the project. They too, made it a success.

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1.0 INTRODUCTION

Corrugated containers are used to package between 90 to 95% of America's total manufactured goods (FBA, 1984). It is well known that the corrugated shipping container serves the four primary functions of a package, these being to contain, protect, communicate, and perform within economical constraints (Anthony, 1983). The grocery industry loses more than 2 1/2 billion dollars each year to damage that could be eliminated by stronger containers (Rogerson, 1988). Compression strength is the measure of a container's ability to ultimately protect the contents. For packaging professionals, a thorough knowledge of compression strength as it relates to the protection function will help to design a more efficient, economical shipping container.

In most cases, the factors affecting the compression strength of the RSC style corrugated shipping container have been well studied. The extensive research conducted includes studies on environmental conditions, duration of load, warehouse handling, stacking pattern, and pallet overhang (Godshall, 1968; Peleg, 1985). Additionally, modifying factors i.e., shape, size, flap gap, and box composition have also been studied with conclusive results on how they relate to, and effect the compression strength of a container. (Peleg, 1985; Maltenfort, 1988). However, one of several other factors that has not been well defined is the effect of printing (Stein, 1975; Maltenfort, 1988).

Printing can be ultimately defined as being directly related to the communication function; since that is how both product identification and information, and in some cases point-of-purchase display information is placed on the shipping container. Flexographic printing will, to some degree, have a detrimental impact on the compression strength of the package; which in turn, will have an adverse effect on the product protection function (Nordman et al., 1978).

Engineers are most often faced with a variety of packaging development situations. One of these is to find a parameter level that will improve some performance characteristic to an acceptable level (Montgomery, 1984). When searching for improved, efficient package designs, the engineer typically runs a standardized test, observes some response (output), and makes a decision based upon the results. It is the quality of this design that can be improved upon when effective test strategies or statistical experimental designs are utilized (Ross, 1988).

According to Barker (1985), experimental design is a structured set of coherent tests that are analyzed as a whole to gain understanding of the process. Barker goes on to state that an efficient experiment gets the required information at the least expenditure of resources.

By using Taguchi's Orthogonal Arrays (Taguchi Techniques) for the statistical design of this six-factor experiment, eight test treatment combinations per printing plate (rubber, photopolymer) type were run. A full-factorial design would require 64 treatment combinations per printing plate type (Table B-1) and a half-fractional factorial would require 32 treatment combinations (Table B-2). The efficient Taguchi Techniques (Table B-3: L8 design for six factors, two levels) for the statistical experimental design of this study allows the use of eight treatment combinations (Taguchi, 1989).

This study examines flexographic printing (the most common type of decorative printing for corrugated) and its effect on the RSC style corrugated shipping container. The objectives of this study are as follows:

1) To evaluate the effect of flexographic printing on the compression strength of corrugated containers.

2) To evaluate the compression strength of control boxes against those subjected to flexographic printing to determine if a correlation exists between specific printing factors.

3) To test different container systems (B & C Flute) to determine if a general pattern exists between material properties and corrugated container compression performance after flexographic printing.

2.0 LITERATURE REVIEW

Hakan Markstrom (1988) stated that compression strength constitutes a general measure of the performance potential of a corrugated package. Compression strength is directly related to stacking performance in a warehouse situation (Maltenfort, 1989). Our review of the literature showed that of the many performance factors of corrugated boxes, compression strength continues to be widely studied.

One of the most well-known empirical formulas commonly used for predicting stacking strength was developed by R.C. McKee. McKee's (1963) formula takes into account the edgewise compressive strength, board caliper, and container perimeter. Through extensive testing of various paperboards and RSC style containers, McKee found that the centermost sections of the panels, as compared to the corners, carry only 1/2 to 2/3 of the load. Therefore, McKee determined that the maximum compressive strength of the container is reached when the board fails near a corner of the panel. Once this happens, the failure continues from the corners to the panel center. It can be concluded that the edgewise compressive strength can be used to predict the maximum compressive strength of the RSC style container (Peleg, 1985).

Compression strength varies with environmental conditions, such as humidity and temperature. In their research on board moisture content and top-to-bottom compression strength, Kellicutt and Landt (1951) concluded that the relationship between the RSC style container's compressive strength and the percentage of moisture content of the board were nearly linear and were inversely proportional. Based on their data, they derived a formula to predict the stacking strength loss of RSC style containers at high moisture contents.

Long-term storage was addressed in extensive research by Hanlon (1984). He provided a guideline for predicting stacking strength during long-term storage. Hanlon recommends using one-fourth of the compressive strength of a corrugated box as a safe load. Kellicutt and Landt (1951), Moody and Skidmore (1966), Koning and Stern (1977), also studied duration of load and its link to failure based on creep properties during long-term storage. They concluded that there is a high correlation between duration of load and secondary creep rate. The equation they developed can be used to predict time to failure for stacked, corrugated containers.

Warehouse mishandling and stacking patterns as they effect compression strength were researched extensively by Ievans (1975). In his studies, he was able to confirm and provide actual data showing the compression loss of containers as it relates to the percent of pallet overhang, misalignment of boxes, interlocking versus straight stacking patterns, and the effects of pallet surface variations.

In the transportation environment, shock and vibration differ in the effect they have on the ability of the container to protect its contents. Godshall (1968) determined that the effect of vibration on the compression strength of corrugated was negligible. On the other hand, Singh's (1987) research on mechanical shocks concluded that multiple handling can result in as much as a 75% loss of the original compressive strength.

Handholes also affect compression strength. Peleg (1985) reports that handholes reduced the stacking strength of a container by approximately 15-20%. Numerous studies by Peters and Kellicutt (1959) compared the impact of location and size of handholes on compression. They found that the reduction in compressive strength usually remained below 10% as long as the amount of area removed was in accordance with the carrier regulations. Unfortunately, testing has rarely been done to evaluate if the container will still handle the intended load when the handholes or die cuts are removed (Maltenfort, 1988). As a result, numerous lawsuits have been filed with the container manufacturers and it has been recommended that disclaimers be placed on the containers, "use handholes at your own risk" (Browning, 1984).

The increased use and requirement for recycled fibers during the production of corrugated containers also results in a decrease of top-to-bottom compressive strength (Koning and

Godshall, 1975). As a result of their work, it can be concluded that heavier paperboard will be needed to meet the specified stacking strength requirements of the future (Peleg, 1985).

The traditional Mullen test is still used by many companies to specify corrugated containers (Peleg, 1985). The significance of the Mullen (burst) test as defined by Tappi T807-os 75 is as follows:

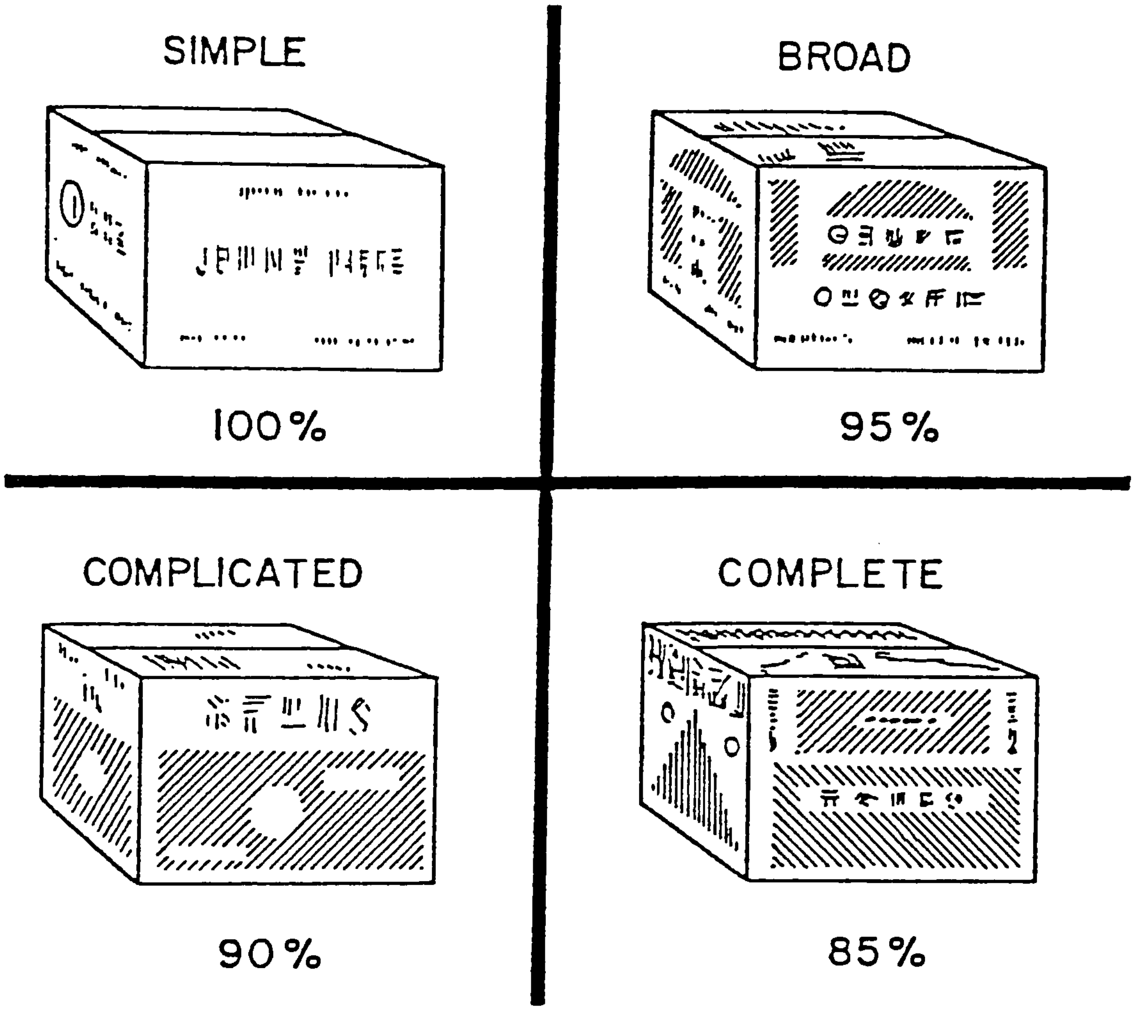
> "The bursting test of paperboard, including linerboard, is a composite measure of certain properties of the sheet structure, principally tensile strength and elongation. In general, bursting strength is dependent on the type, proportion, preparation, and amount of fibers present in the sheet and to their formation, internal sizing, and to some extent surface treatment. Bursting strength, in combination with basis weight, serves to define 'standard grades' in commerce."

It was determined in research by Fox, et al., (1978) that RSC style shipping containers actually only failed in compression when loaded internally (i.e., the pushing from the inside to the outside of the box caused by slightly overfilling the container). The main cause for failure was tensile versus from compressive forces applied by outside pressure. This research effectively eliminated the validity of the Mullen test's measure of tensile strength as a correlation to corrugated's performance of compression.

Other factors that modify the compression strength would include perimeter, shape, board weight, flute type, flap gap, container inserts, and manufacturer's joints. Ongoing research continues to document the effect of these factors on the overall compression strength of corrugated (Maltenfort, 1988).

A review of the literature finds extensive research in almost all facets of the compression strength of corrugated except printing. References addressing printing (Stein, 1975; Maltenfort, 1988) are at best, vague and non-measurable, (Figure 1). Print crush is often addressed instead of compression strength (International Paper Company; Bonza, 1988). However, corrugated suppliers do recognize that if the board is crushed during manufacture (i.e., by heavy printing), that the compression strength will be reduced (Stone Container Corporation, 1989).

Ultimately, we feel that printing is an area that calls for more definitive information as it relates to the compression strength of an RSC style corrugated shipping container.



NOTE: IF THERE IS NO PRINTING THE FACTOR IS 100%

FIGURE 1: Container-Quinn Laboratories modifying factors for printing.
*Illustration courtesy Container-Quinn Laboratories

3.0 MATERIALS AND METHODS

3.1 Sample Containers:

Two sets of regular slotted containers (RSC) were utilized in conducting the research.

Box 'B' Specification:

Paperboard:	B flute, double faced, single wall
Dimensions *(outside):	16" x 12" x 11" (L x W x D)
Bursting Test:	200 pounds per square inch
Minimum Combined Weight of Facings:	84 pounds per 1000 square feet (Balanced Liners: 42)

Box 'C' Specification:

Paperboard:	C flute, double faced, single wall
Dimensions (outside):	16" x 12" x 11" (L x W x D)
Bursting Test:	200 pounds per square inch
Minimum Combined Weight of Facings:	84 pounds per 1000 square feet (Balanced Liners: 42)

* Outside dimensions were used to facilitate obtaining the correct percentages when calculating the "amount of print" factor.

The 16" x 12" x 11" (L x W x D) external dimensions of the test box were selected since it was the standard size used for an extensive amount of the compression testing conducted by Container Corporation of America (Maltenfort, 1956). A CAPE (1989) pallet analysis also shows this size container optimizes the total shipping cube usage on a standard U.S. 48" x 40" pallet (Figure 2).

Cube Efficiency: 97.8%
Area Efficiency: 100.0%

10 Cases/Layer
4 Layer/Load
40 Cases/Pallet

DIMENSION

	Length	Width	Depth	
Cases	16.000	12.000	11.000	inch
Load	48.000	40.000	49.500	inch

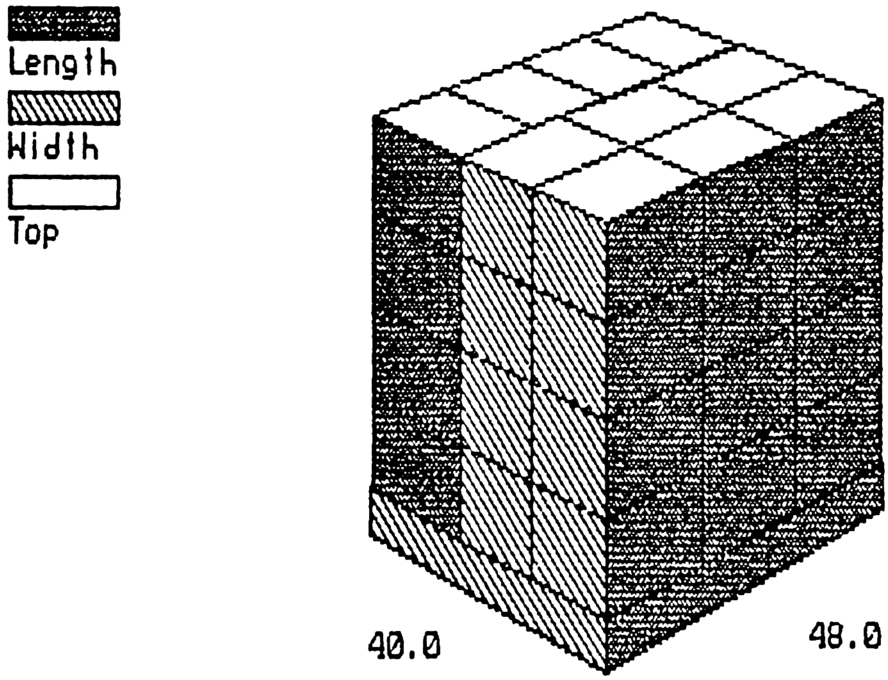


FIGURE 2: CAPE Pallet Analysis

The 200 lb. burst test paperboard selected for this research was also common to many of the previous compression strength studies completed (Maltenfort, 1956; Fox, 1978).

The boxes were manufactured by Mohawk Containers of New Hartford, New York for Mobil Chemical Company, Plastic Packaging Division.

3.2 Printing Plates:

The use of two different types of printing plates allowed two separate groups of data to be collected while at the same time providing an additional modifing factor to be analyzed (photopolymer, rubber). The print miniatures for the various treatment combinations used in the research and model verification are shown in Tables C-1 and C-2 respectively.

Printing Plate 'P' Specification:

Material:	W.R.Grace Flexo Photopolymer
Thickness:	.240"
Durometer:	35

Printing Plate 'R' Specification:

Material:	Econo Natural Rubber
Thickness:	.240"
Durometer:	35

The printing plates were manufactured by Matrix Unlimited, Incorporated of Rochester, New York for Mobil Chemical Company, Plastic Packaging Division. Doublesided stickyback

(.010" thickness) was used to mount both types of printing plates to the plastic mounting board (Mylar, .030" thickness) (Toepfer, 1990). The dimensions of the printing plates for the various factors studied are recorded on the print miniatures included in Table C-3.

3.3 Manufacture and Printing of Containers:

The flexo folder-gluer used for the production of the test boxes was a Langston Flexo made in Camden, New Jersey. Its serial number is 792986, was shipped in October 1979 and at Mohawk Container is identified as Line 36. This particular piece of equipment is capable of handling corrugated sheets up to 110" wide.

Production Line Operating Conditions

Speed: 180 boxes per minute maximum
90-120 boxes per minute (110 average) during printing of test boxes
140 boxes per minute during production of control boxes

Gap Between Plate and Impression Cylinders:

	press 1*	press 2
C flute	.425"	.425" 1/2-color
B flute	.400"	.400" 1-color
		.360" 2-color

* Press 1 is the one closest to the feeder.

There were no pull bands required as the blank sheets were wide enough to be pulled through by the cylinders.

The inks used for the printing were as follows:

Huberflex Water Based Flexographic Ink, J.M. Huber Corporation, Edison, New Jersey.

1-color print (press 2)	156 B 731, 31 blue
2-color print (press 1)	156 R 774, 74 red

These are the standard inks used when blue and/or red colors are specified for Mobil Chemical Company orders. Figure 3 depicts the schematic of a flexo folder-gluer.

All the C flute test boxes were run during the first day of production and 25 boxes were run for each sample required. The test boxes for B flute were run on the second day. Within each flute, the single color boxes were run first. The other factors were run randomly. The same operator and two assistant operators ran the line on both days.

The containers were shipped direct from Mohawk Containers to Mobil. They were then forwarded to the Central Packaging Laboratory facility at Kodak. They arrived in a knocked-down condition on 3-1/2 pallet loads. There were 4 bundles per layer, 20 bundles per full pallet load for a total of 1,750 boxes. A slip sheet was placed between the layers and the load was contained with 2 plastic straps. Each bundle of 25 containers was individually strapped across the flaps with plastic strapping in an effort to minimize damage to the samples. Individuals were notified along the entire shipping

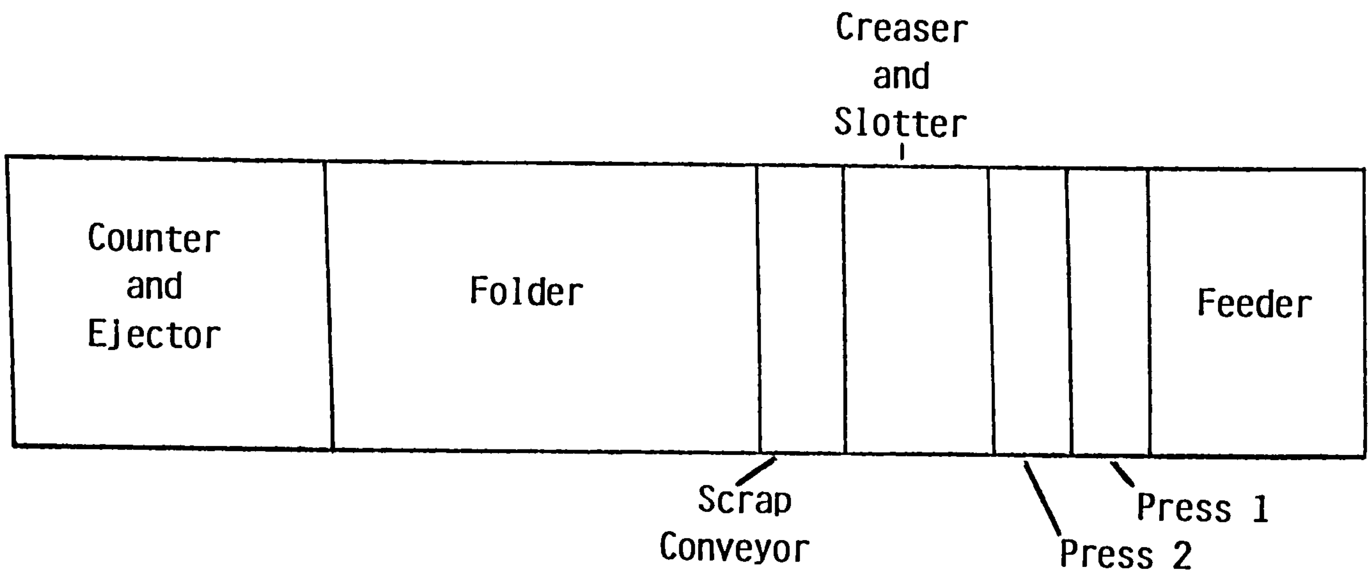


FIGURE 3: Schematic of a Flexo Folder-gluer.

route to ensure special, careful handling of the test containers. This was done to keep damage encountered during shipping to a minimum.

The shipment arrived at Kodak one day before the preconditioning chamber became available. The containers remained palletized in the controlled testing laboratory environment until they were moved to the preconditioning chamber.

3.4 Test Methods:

3.4.1 Preconditioning:

The knocked-down containers were moved by hand into the Russell chamber, Model WM-2280-15 for preconditioning. Performance capabilities and design specifications as stated in the operating manual are in Figure 4. The containers were propped into a vertical orientation on pallets throughout the chamber, and the plastic strapping was removed from each bundle to enhance air flow between the samples. Slip sheets were placed between the bundles for ease of handling and identification.

All samples were preconditioned according to ASTM Standard D 685-73 at 100°F. and 20% RH. ASTM Standard D 685-73 states that preconditioning on the dry side avoids most of the hysteresis effect and results in the moisture content of the sample being within the defined parameters of 0.15% when it

PERFORMANCE SPECIFICATIONS

Temperature Range:

0 to +85 degrees Centigrade (C)

Humidity Range:

20 to 95% RH as limited by a +3 degree C dewpoint and + 70 degree C dry bulb and a + 63 degree maximum dewpoint temperature.

Control Accuracy:

+/- 1 degree C dry bulb and wet bulb air temperature control tolerance as measured at the control sensor after stabilization.

Temperature Gradient:

The temperature within the test chamber workspace will be maintained within +/- 2.2 degrees C of set point as measured after stabilization, with an empty chamber, and as measured 6" from any surface.

Interior Dimensions: (approximate)

12' wide x 19' deep x 10' high

Exterior Dimensions: (chamber proper)

12'8" wide x 21'8" deep x 10'4" high

Refrigeration System:

15 Horsepower, (1) 15 HP compressor
Refrigerant 502, water-cooled"

FIGURE 4: Russell Chamber Performance Specifications

is later conditioned at 73°F. and 50% RH. Temperature and relative humidity were monitored by a Micristar advanced microprocessor based digital process controller (Specs at Figure 5).

3.4.2 Conditioning:

The samples remained in the Russell chamber for conditioning. In accordance with ASTM standard D 685-73, temperatures were set at 73°F. and 50% RH.

Samples remained in the chamber for 45 hours prior to testing to ensure sufficient time to come to equilibrium. Peleg (1985) stated that for corrugated paperboard containers, equilibrium moisture content was generally reached after approximately 8 hours. Therefore, he concluded that a minimum of 12 hours of conditioning was sufficient in most cases. Since the laboratory was not equipped to test for moisture content of corrugated materials, we chose to precondition the samples for a sufficient time so we could assume an equilibrium without the benefit of the moisture content test (Peleg, 1985).

3.4.3 Testing Procedures:

After conditioning, all samples were moved by hand into the adjacent testing room. Containers were set-up and sealed as described in ASTM standard D 642-76. Scotch Brand high per-

PERFORMANCE SPECIFICATIONS

PROGRAMMER UPDATE TIME	0.2 seconds
CLOCK ACCURACY	0.005% of elapsed time
PROCESS VARIABLE INPUTS	
Minimum Span	10 mv
Resolution	12 bits (0.025%)
Sampling Rate	5 samples per second
Conformity (Thermocouple or RTD)	+0.3% of span
Nonlinearity	+0.1% of span
Accuracy	+0.1% of span
Repeatability	+.05% of span
Noise Rejection	
Normal Mode	Determined by selected filter value
Common Mode	Greater than 120 db at 60 Hz
Isolation	1000 VAC
PROCESS CONTROL OUTPUTS	
Update Time	0.2 seconds
Resolution	10 bit (0.10%)
CONTROL STABILITY	Ambient temperature affects put by 0.02% of input span per degree C.
POWER	120 or 240 VAC (+10%, -15%) 47 to 63 Hz
ENVIRONMENTAL LIMITS	
Temperature	Operating: 0 to 50 degrees C Storage: -40 to 60 degrees C
Relative Humidity	0-90%, non-condensing

FIGURE 5: MICRISTAR Performance Specifications, Page 1-12

formance box sealing tape (3750) from the 3M Packaging Systems Division was used for case closure. The transparent, pressure sensitive tape was 2 inches wide and met the U.S. Postal Service width and strength regulations.

Testing was done on a Tinius Olsen compression tester (Figures 6 & 7). The machine was set according to ASTM standard D 642-76 using a floating platen and a machine speed of .4 inches per minute deflection. All containers were tested to failure. Force was pre-loaded to 50 pounds manually by the machine operator prior to each sample tested.

While most standard compression testing procedures of shipping containers specify fixed-platen compression testing machines, such machines offer measurement which is less realistic than a floating-type platen (Peleg, 1985). Langlois (1989) compared the use of fixed versus a floating platen during compression testing and found that the fixed platen gave a higher average compression strength value of 3.4%. Langlois strongly recommended that a floating platen be used as a more realistic measure of compression strength.

Guide tape was placed on the lower platten to ensure that each sample was positioned uniformly prior to testing. Samples were always run with the manufacturer's joint facing the operator. Each sample was visually inspected for damage that might have occurred during shipping. Containers with visual

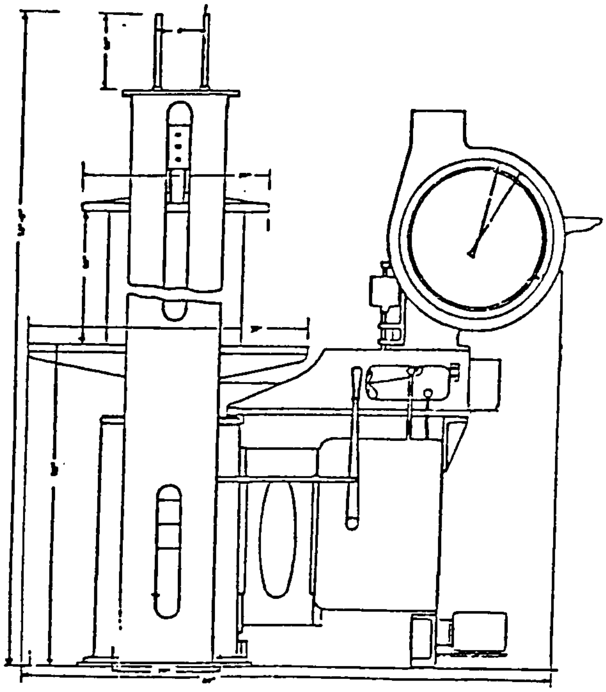


FIGURE 6: Tinius Olsen Compression Tester - Side View, Manual, page 2

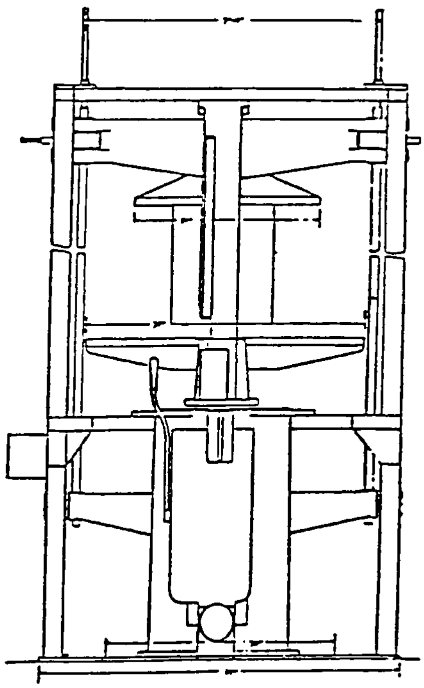


FIGURE 7: Tinius Olsen Compression Tester - Back View, Manual, page 3

damage were rejected prior to compression testing. Deflection and force data were recorded using the Metrosonics dl-721 Data Logger. A detailed record was kept on the damage sustained by each sample tested.

The order of compression testing was random. Test sequence by day is listed in Table B-4. Five samples per bundle were randomly selected (based on visual inspection) from the center of the bundle, excluding the first and last five containers within each stack. Testing was completed over 3 consecutive days. The testing room temperature and humidity varied between 75-76 $^{\circ}$ F. and 56-58% RH (Figure 8). The samples remained within this controlled environment throughout the test period.

3.4.4 Methodology:

To design the experiment for six factors each at two levels, four areas must be covered in detail:

1. Factors and/or interactions to be evaluated.
2. Number of levels for the factors.
3. The correct Taguchi orthogonal array (OA). (Explained in detail on pages 26 through 28)
4. Assignment of the factors and/or interactions to the OA columns per linear graphs.

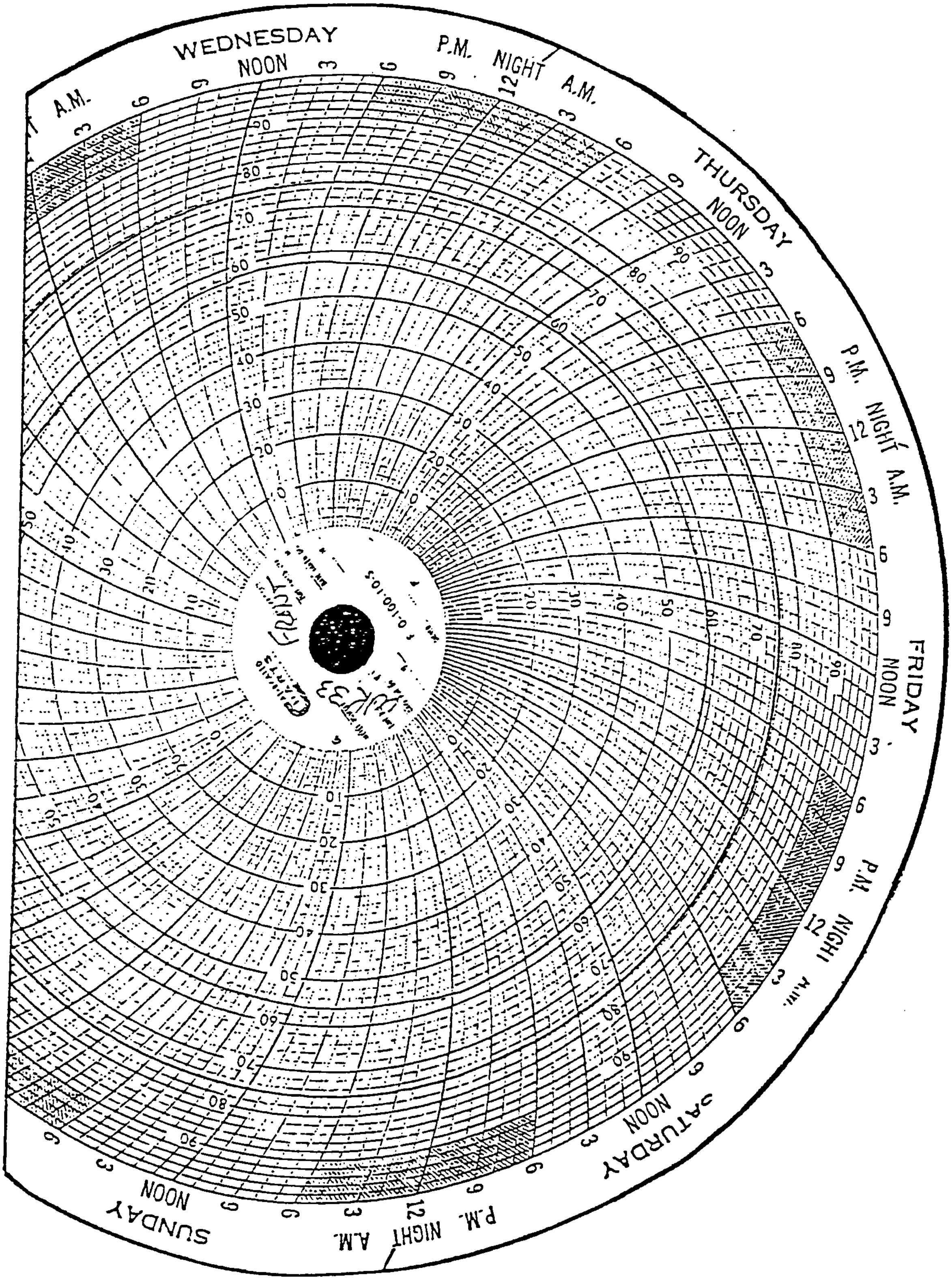


FIGURE 8: Testing Room Temperature and Humidity Graph

After the above four areas have been addressed, then the testing, gathering of data, and analysis of data would follow in order.

In the design of this experiment, we determined that there were six significant factors contributing to the performance of the test containers: Location, panel, amount, colors, flute, and shape. We also expected no interactions to occur in the experiment. An interaction is the result of the non-additivity of two or more factors on the response or performance of the container (Barker, 1985).

Taguchi (1989) recommends that the factors be evaluated at two levels to minimize the size of the experiment. Our design is composed of six factors each at two levels (Table B-5).

Selection of the OA depends on three items:

1. Number of factors (6).
2. Number of interactions, if any (0).
3. Number of levels for each factor (2).

There are four possible two-level OAs to select from (Taguchi, 1989): L4, L8, L12, and L16 (Table B-6 through Table B-8).

We were interested in six factors and no interactions. Keeping in mind an efficient experiment, we selected an L8 OA design. The number in the array is the number of total trial combinations. For example, an L8 OA has a total of eight treatment combinations (TCs) in the experimental design. Or, in other words, it only requires that eight different sets of printing plates be made to evaluate the effect the factors have on the response of the containers. The two factor levels for each of the eight TCs are coded and designated by 1s and 2s. All OAs must be both orthogonal (the effect of one factor does not interfere with the estimation of the effect of another factor) and balanced (an equal number of TCs, "1s and 2s", for each factor)(Barker, 1985). A balanced design guarantees an orthogonal array.

Next, we decided which columns to assign the factors in our design. This requires referring to the linear graphs for the L8 OA (Figure 9). When interactions are present, one would assign factors A, B, C, and D to columns 1, 2, 4, and 7. This would leave columns 3, 5, and 6 open to study the two factor interactions (AB, AC, and BC).

We saturated the L8 OA. When all columns are assigned a factor, it is known as a saturated design. Saturating a design is possible when there are no interactions assigned to columns. We expect no interactions in this experiment. This allows us to study up to seven factors in an L8 OA design.

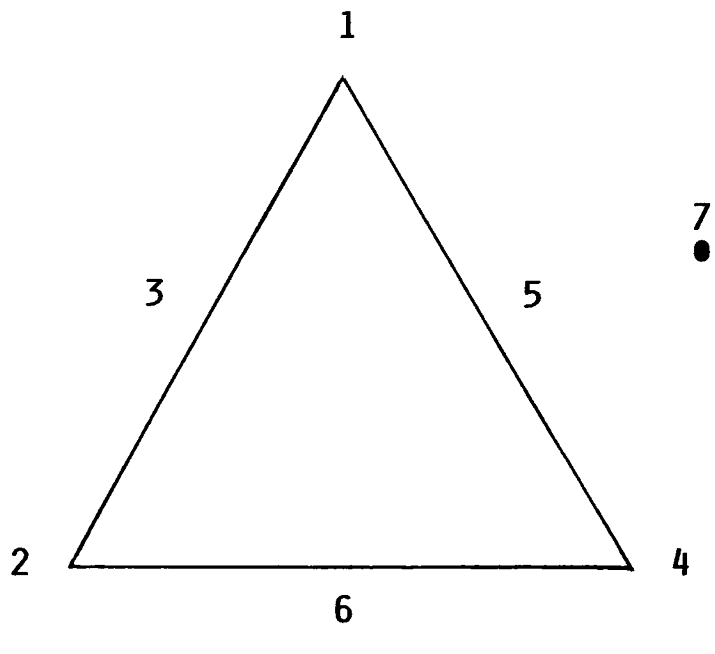


FIGURE 9: L8 Linear Graph

The factors would be assigned to columns as follows:

COLUMN	FACTOR
1	FLUTE
2	COLORS
3	AMOUNT
4	PANEL
5	LOCATION
6	SHAPE
7	No Assignment

Factors were assigned to columns on the basis of restrictions in the production of the containers. For example, column one was assigned to the factor "flute", all B flute (1) is run after changing over from C flute (2) material due to process constraints at the production facility. And, all blue (1) color containers were run prior to blue and red (2) color containers within each flute.

4.0 DATA AND RESULTS

Plotting of the average effects of each factor at their one and two levels resulted in the following:

Photopolymer (Figures 10-14)		Summary
A.	LOCATION	10.6% average drop in compression (center to corners)
B.	PANEL	5.6% average drop in compression (2-panel to 4-panel)
C.	AMOUNT	5.3% average drop in compression (15% to 30%)
D.	COLORS	1.2% average increase in compression (1-color to 2-color)
E.	FLUTE	24.9% average increase in compression (B flute to C flute)

Rubber (Figures 15-19)		Summary
A.	LOCATION	4.1% average drop in compression (center to corners)
B.	PANEL	1.0% average drop in compression (2-panel to 4-panel)
C.	AMOUNT	4.0% average drop in compression (15% to 30%)
D.	COLORS	1.9% average drop in compression (1-color to 2-color)
E.	FLUTE	28.0% average increase in compression (B flute to C flute)

The calculations of the above average responses for photopolymer and rubber plates are found in Tables A-9 and A-10 respectively and are graphed in the figures on pages 30-39.

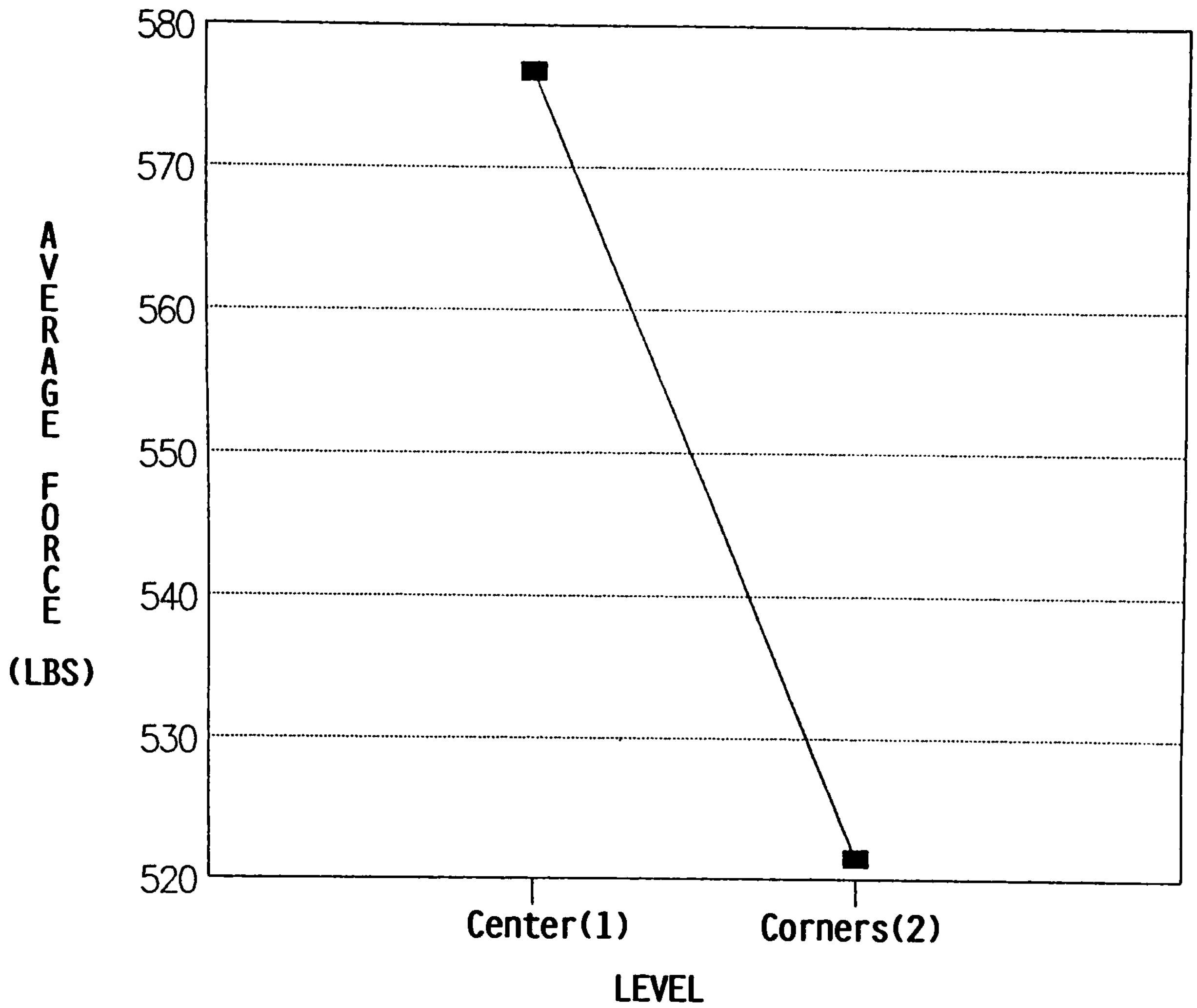


FIGURE 10: Photopolymer - Location Average Effect Graph

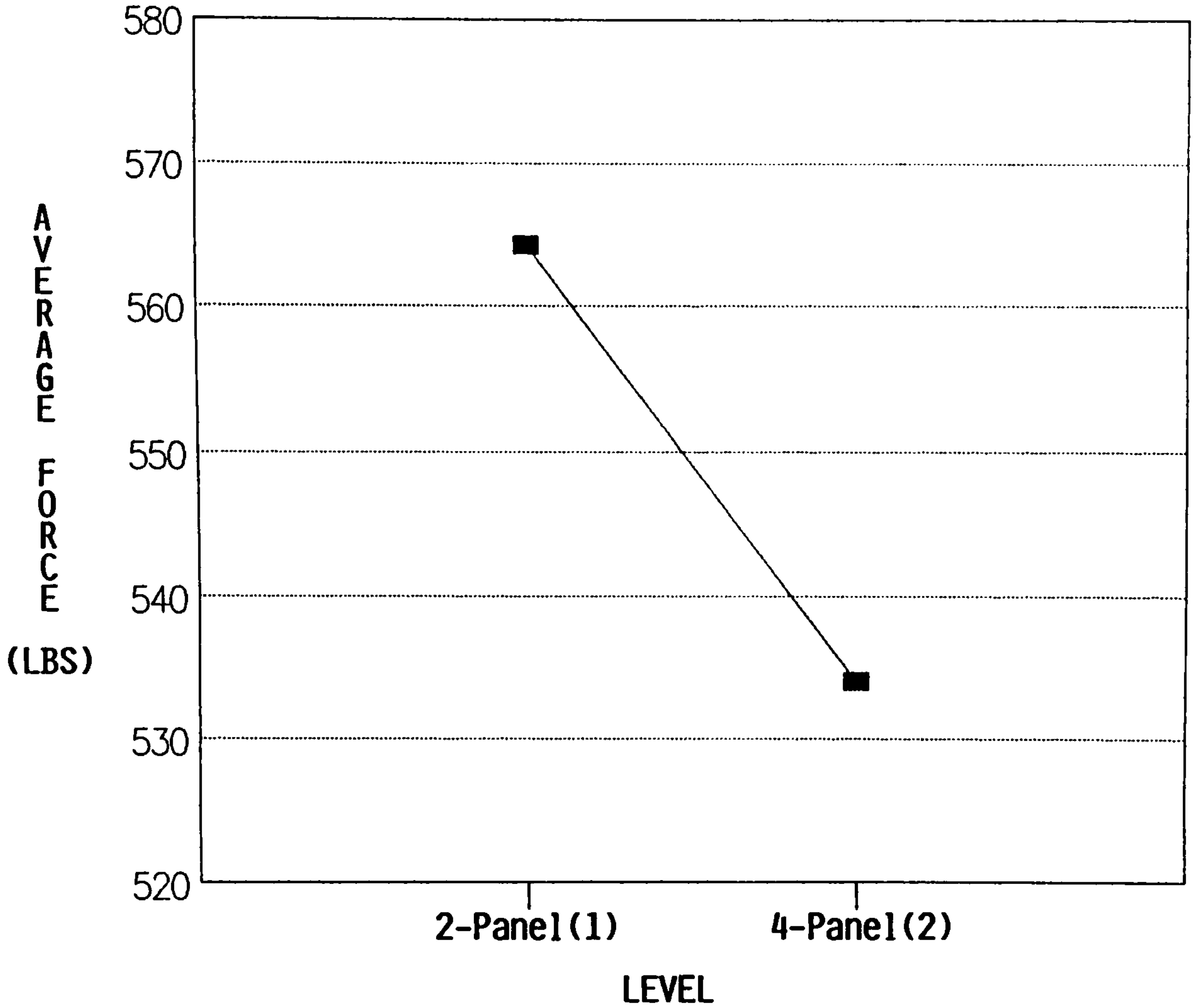


FIGURE 11: Photopolymer - Panel Average Effect Graph

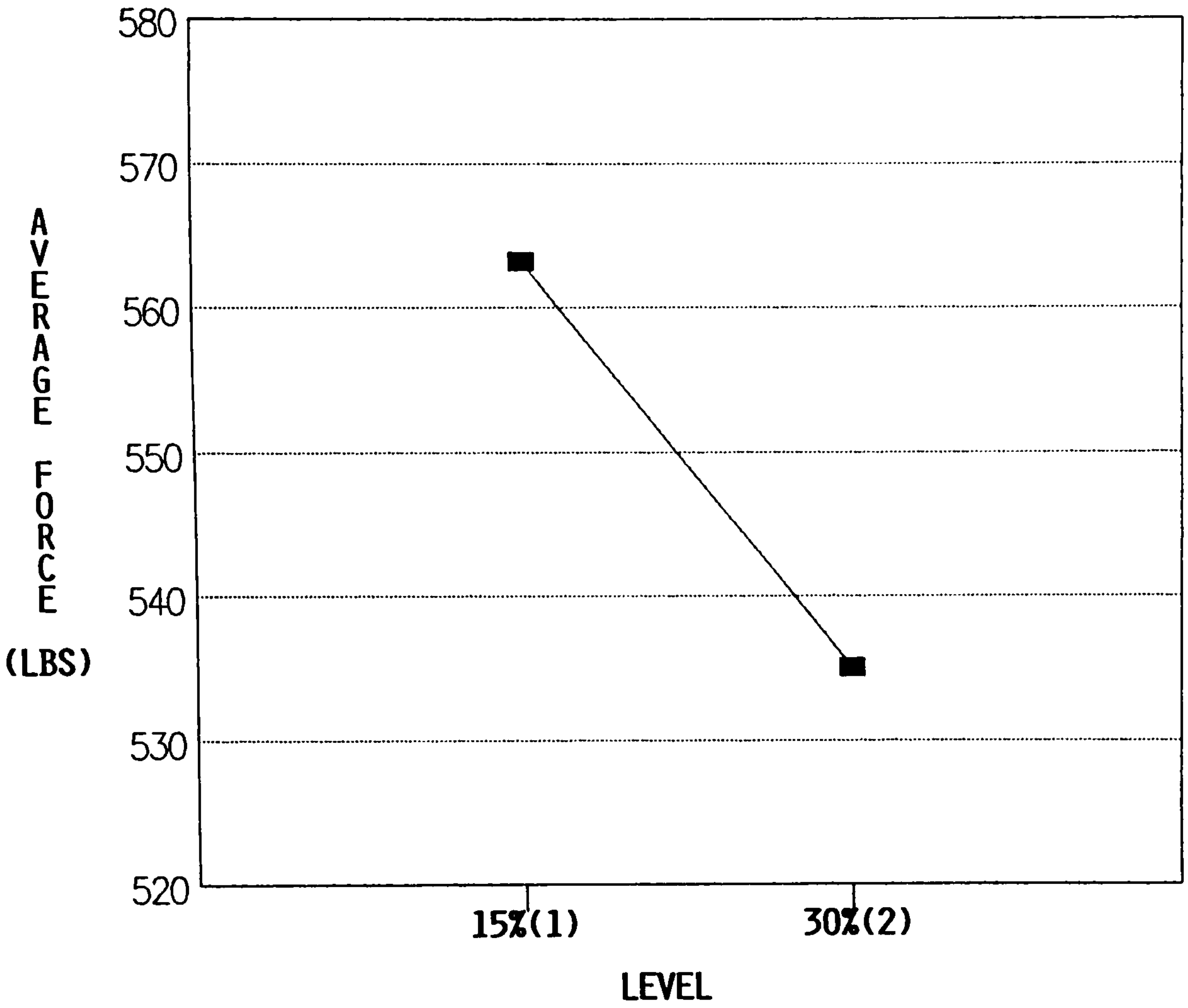


FIGURE 12: Photopolymer - Amount Average Effect Graph

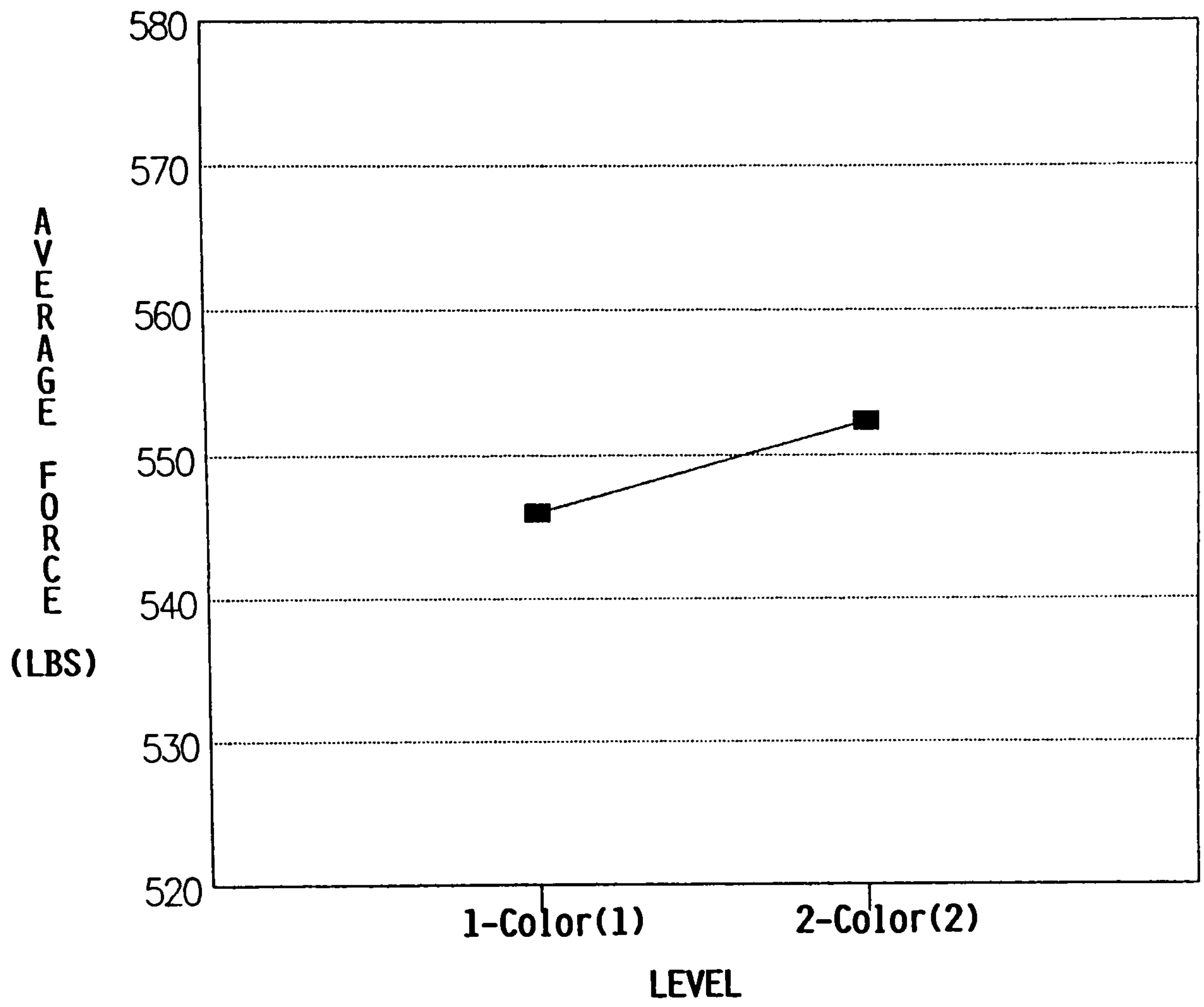


FIGURE 13: Photopolymer - Colors Average Effect Graph

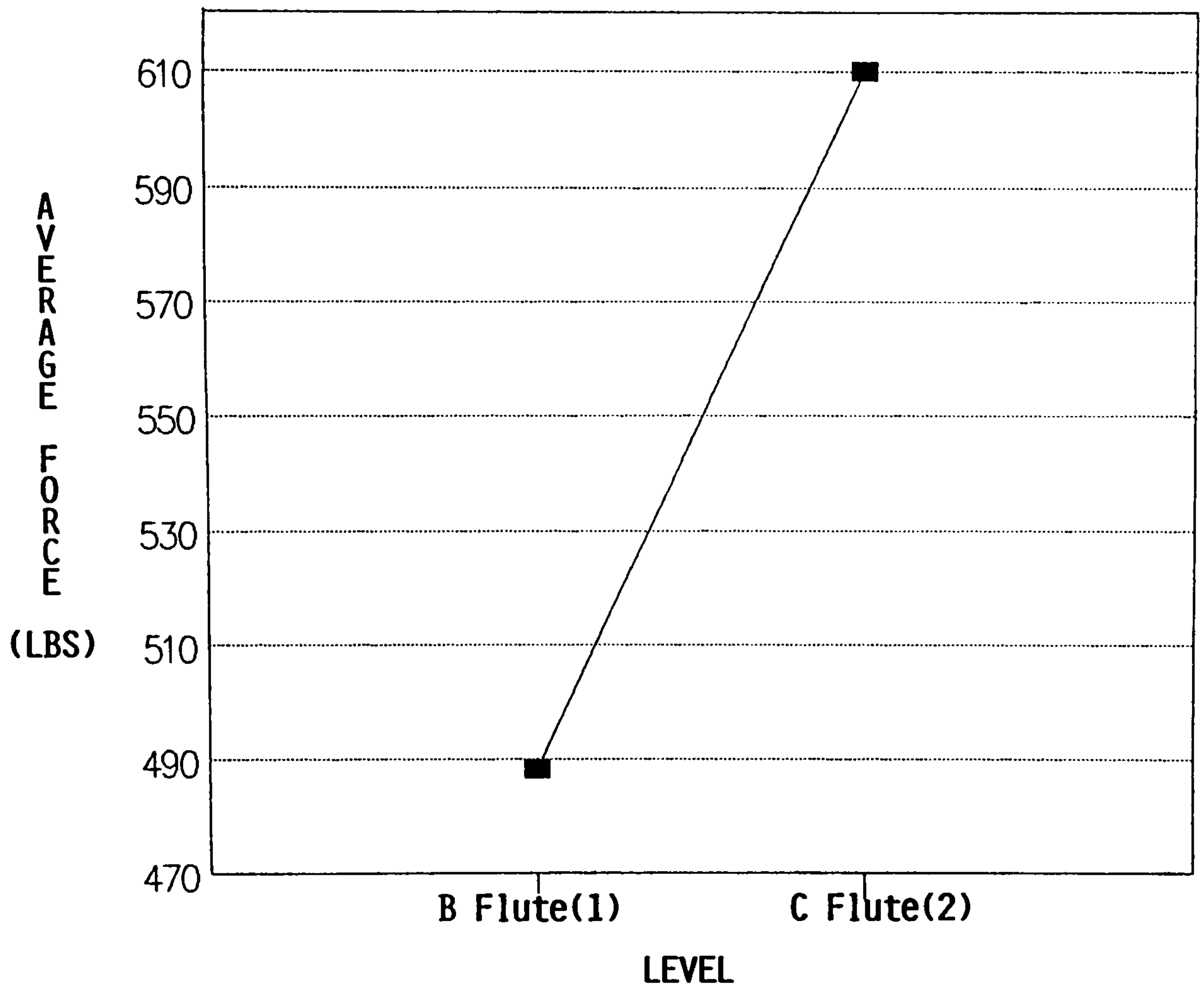


FIGURE 14: Photopolymer - Flute Average Effect Graph

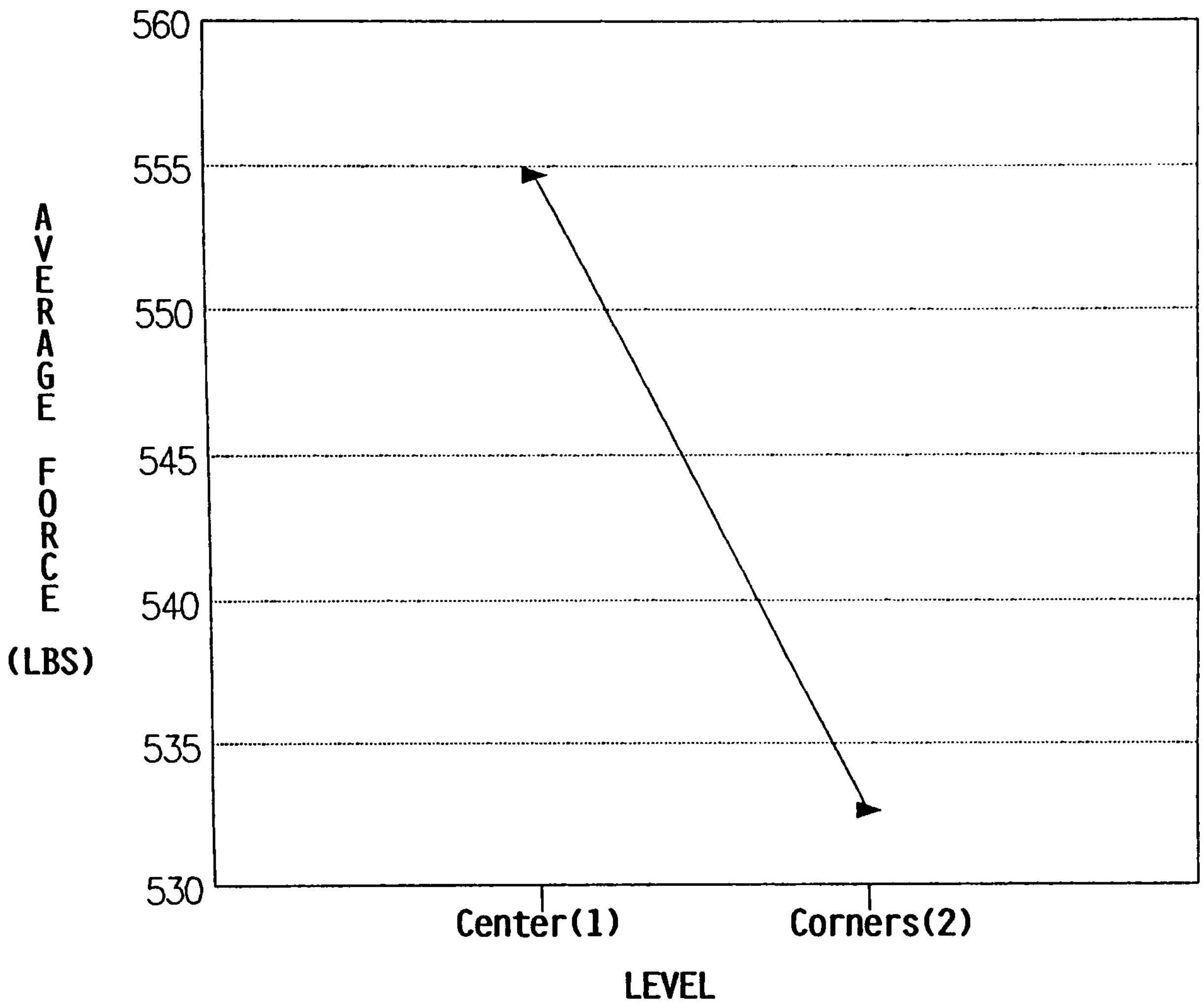


FIGURE 15: Rubber - Location Average Effect Graph

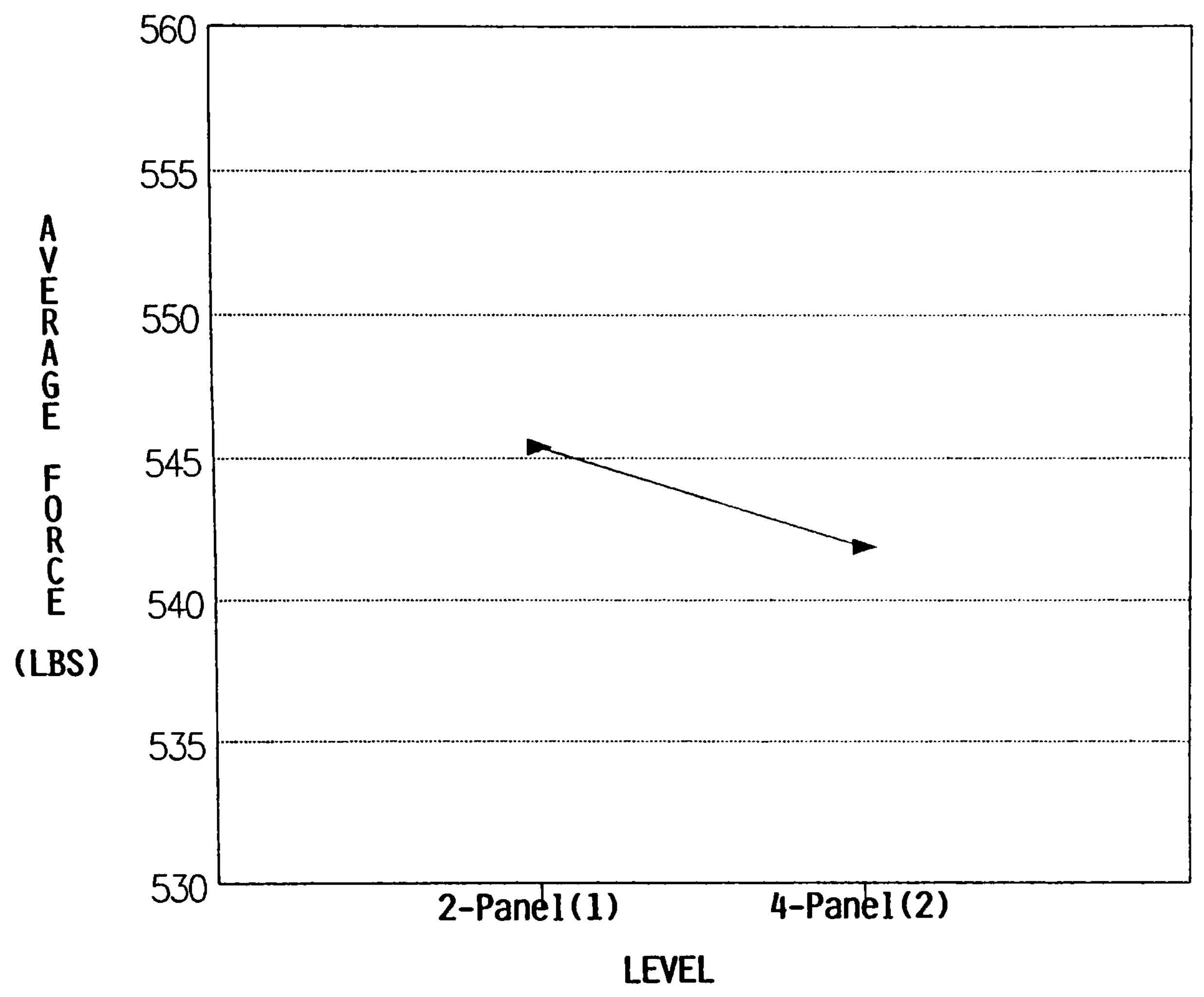


FIGURE 16: Rubber - Panel Average Effect Graph

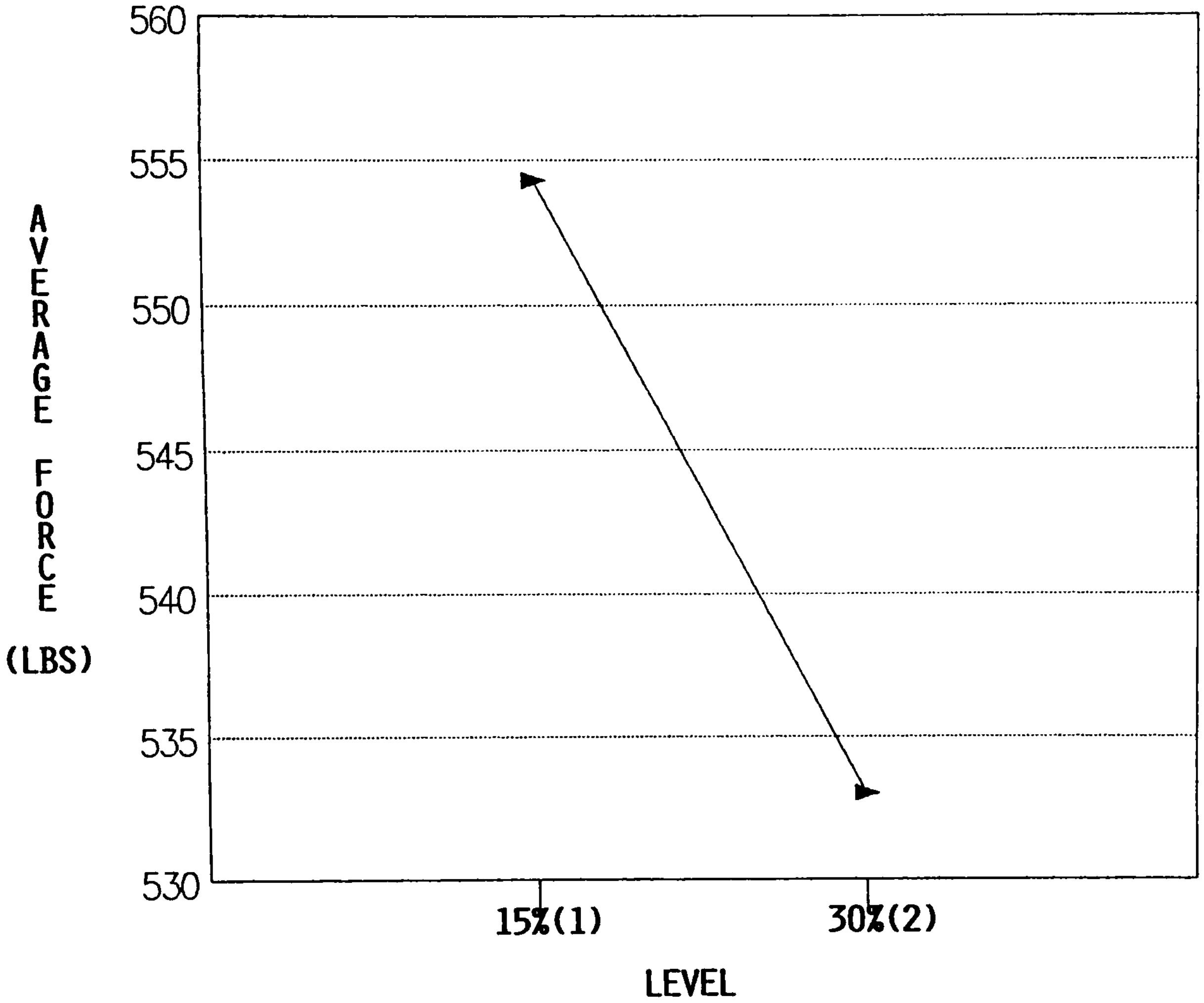


FIGURE 17: Rubber - Amount Average Effect Graph

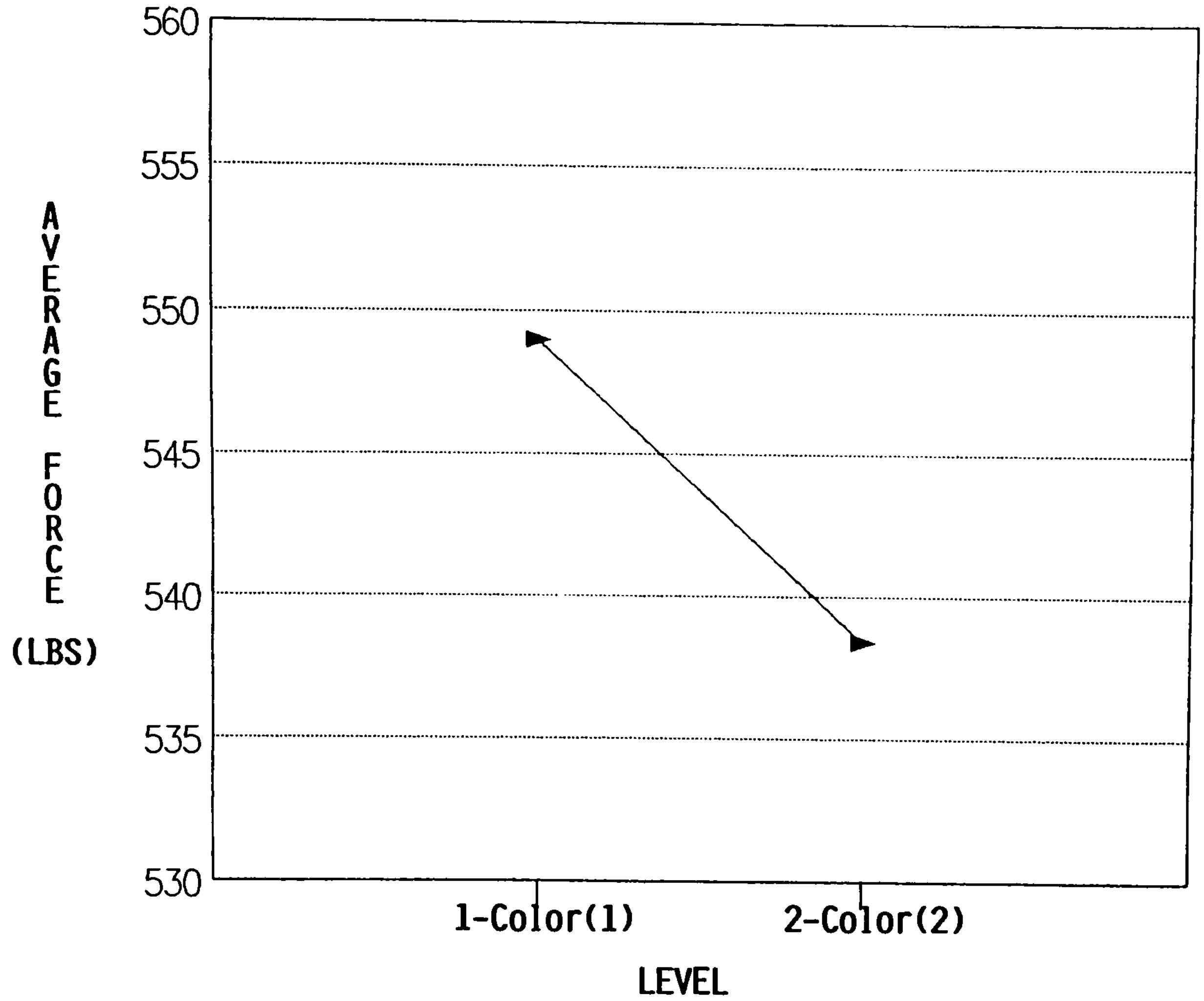


FIGURE 18: Rubber - Colors Average Effect Graph

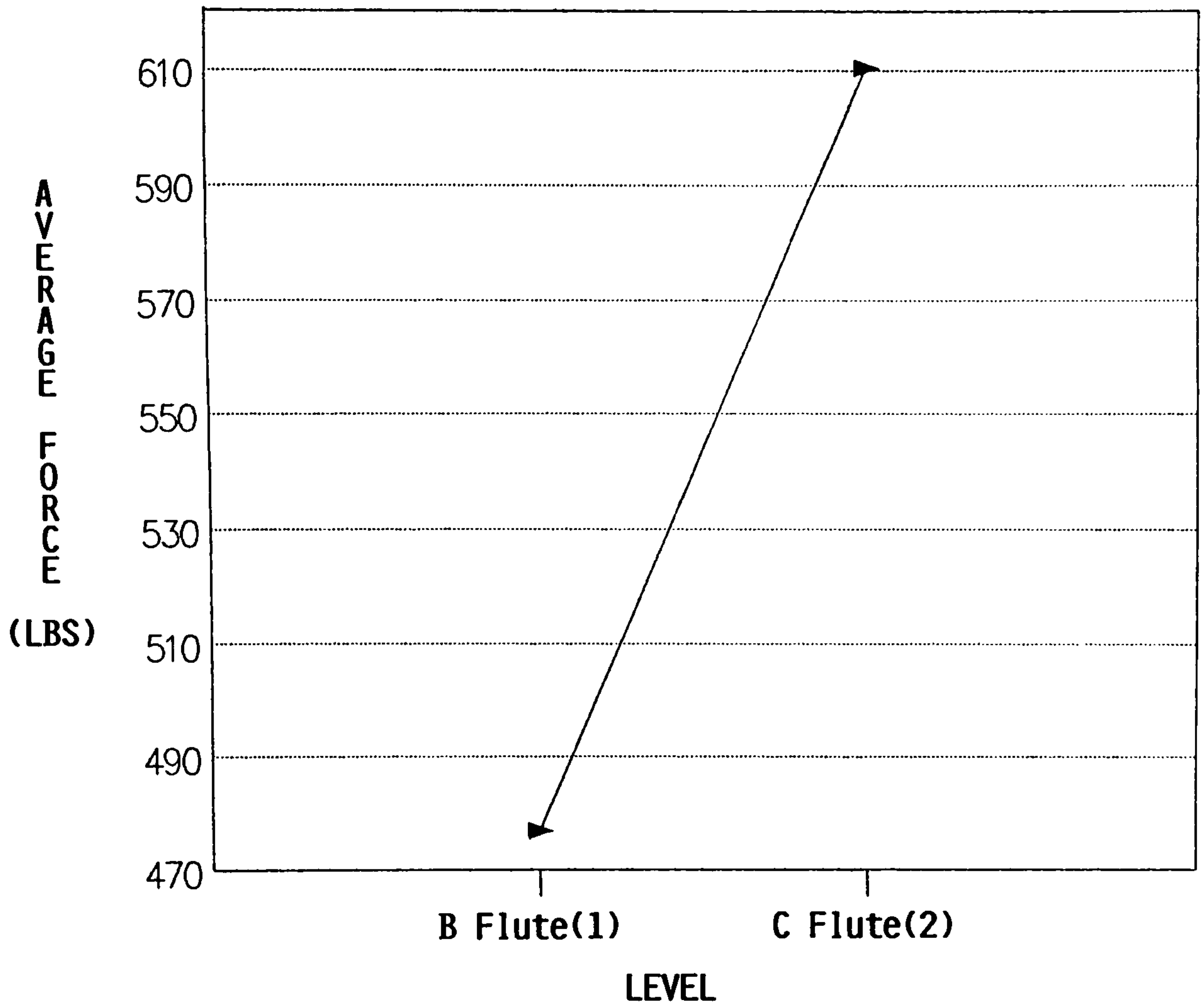


FIGURE 19: Rubber - Flute Average Effect Graph

The summary data for B and C flute are shown in Table A-1. Tables A-2 and A-3 display the data in average effect order. Tables A-4 through A-8 reflect the actual compression and deflection test results for all runs.

The results of the analysis of variance test (ANOVA)(Minitab, 1989) on the five factors in the photopolymer experiment showed all the factors except colors as being significant (Table A-11). Thus, over the range of results in the experiment, all (but color) had a significant effect on the compression strength of the RSC style container.

The results of the ANOVA (Minitab, 1989) on the five factors in the rubber experiment revealed two significant factors: location and flute (Table A-12). Thus, only location and flute had a significant effect on the compression strength of the RSC style container.

We used Minitab (7.0) to do a simple multiple linear regression of the test data using least squares to fit a model to more than one predictor. The basic least squares regression model is:

$$Y = b_0 + b_1 A + b_2 B + b_3 C + b_4 D + b_5 E$$

Y = predicted value = compression
b_0 - b_5 = regression coefficients
A - E = predictors (factors of the experiment)

Note: Regression is the same as ANOVA, if the design is orthogonal (and balanced). (Minitab, 1989)

Model for Photopolymer:

Compression = 527 - 55.5 (Location) - 30.4 (Panel) - 27.9 (Amount) + 6.6 (Color) + 122 (Flute)

Model for Rubber:

Compression = 432 - 25.1 (Location) - 6.6 (Panel) - 18.3 (Amount) - 7.6 (Color) + 132 (Flute)

Four more treatment combinations were run to verify the general model for both the photopolymer plate and rubber plate experiments (Figure 20). Preliminary indications, using the additional four samples run, appear to support the model's usefulness. More runs are needed to determine the model's validity for future use.

4.1 Discussion:

Although the actual compression test conditions of temperature and humidity were outside of ASTM standards, the results were consistent over the 3 days of testing. It is expected that due to the higher temperature and relative humidity, the average compression strength results were lower (Maltenfort, 1988).

Due to some statistical design problems, one factor was eliminated from the original design. Shape of print was excluded

*CODE	PLATE TYPE	COMPRESSION (lbs) PREDICTED	ACTUAL	% DIFFERENCE
	Photopolymer:			
23PB	2 1 1 1 1	486.3	453.3	- 6.8
16PC	2 2 1 1 2	577.9	576.7	- 0.2
	Rubber:			
8RB	2 2 1 1 1	474.7	494.1	+ 4.1
14RC	2 2 2 2 2	580.8	575.5	- 0.9

* The numerical portion of the code was assigned for operator tracking purposes only and has no statistical significance. The remaining code is deciphered as follows:

R = Rubber Plates; P = Photopolymer Plates; B = B Flute; C = C Flute

FIGURE 20: Test Model Verifications

from the analysis because we failed to run it in a balanced design as required by the Taguchi Technique.

There also appeared to be some problems associated with the manufacture and printing with rubber plates of the B flute containers. As a result, the data collected during the compression testing was not consistent and we were forced to run four of the treatment combinations with less than five replications each. This results in a lower confidence level in the results for rubber printing plates.

It was specifically noted that shipping damage had occurred with the original C flute control samples, however, a second test was conducted from new samples with good results. Shipping damage was probably also associated with the B flute controls (Table A-4).

In the rubber printing plate on B flute, the following number of replications were used for the first four runs of the L8 OA:

Run 1	2 replications
Run 2	3 replications
Run 3	1 replication
Run 4	2 replications

The sensitivity of the five replications run provides a 90% confidence in detecting a change in average of about one standard deviation. Dropping to one replicate per trial results in a 90% confidence in detecting a change of approximately two standard deviations.

The use of a full, flat printing plate surface during this research reflects a worst case scenario for printing. The crush was probably more severe than would be encountered during normal printing since increased pressure was required to obtain full and uniform coverage on the samples.

Based on the statistical analysis of the data, the number of colors (1-color, 2-colors) did not appear to significantly affect the compression strength of the samples. The increase in compression strength going from 1-color to 2-colors when printed with photopolymer plates is an anomaly that cannot be readily explained.

In the late 1970s, the introduction of built-in compressible backings for photopolymer printing plates allowed the use of more precise plates which do not require excessive pressure to ensure good plate contact with the board (Schulman, 1986). This fact may also account for some of the difference or variance between the photopolymer and rubber results.

5.0 CONCLUSIONS

The compression strength of an RSC style container will be altered by varying the printing location, amount, panels printed, type printing plates and paperboard flute, as this experiment demonstrates. Current methods of printing, to include the placement of UPC symbol and private label print requirements, illustrate that printing factors and their effect on compression strength, are often not considered during package design.

The effect of the printing variables studied in this research on the overall compression strength of an RSC style container should be considered as a modifying factor. Thus, printing factors must also be evaluated prior to designing for safe warehouse stacking heights.

An L8 OA Taguchi design is an effective and efficient method of experimental design.

6.0 RECOMMENDATIONS

As printing plate technology continues to improve providing a finer quality print (Shulman, 1986), more research will need to be done to determine the ultimate effect on the compression strength of the RSC style corrugated container. We strongly recommend future studies look independently at each one of the print factors identified. An in-depth investigation of these factors will confirm a definitive and measurable relationship as was illustrated by our predictive regression equation.

APPENDIX A

TABLE A-1: B and C FLUTE DATA SUMMARY

(This information corresponds to data shown in Tables A-2 and A-3 on pages 48-49)

B FLUTE

*CODE	MAX FORCE	MAX DEFL		CODE	MAX FORCE	MAX DEFL
20 PB	578.3	0.273	*	20 RB	481.5	0.313
33 PB	420.1	0.259	*	33 RB	481.9	0.300
34 PB	483.8	0.273	*	34 RB	447.3	0.259
4 PB	471.1	0.253	*	4 RB	504.1	0.253
8 PB	486.3	0.273	*	8 RB	494.1	0.266
23 PB	453.3	0.280	*	23 RB	427.6	0.253

C FLUTE

CODE	MAX FORCE	MAX DEFL		CODE	MAX FORCE	MAX DEFL
19 PC	576.0	0.326	*	19 RC	593.2	0.353
35 PC	609.5	0.326	*	35 RC	617.2	0.320
12 PC	618.8	0.333	*	12 RC	609.4	0.320
27 PC	635.7	0.340	*	27 RC	622.4	0.333
14 PC	665.4	0.386	*	14 RC	575.5	0.320
16 PC	576.7	0.320	*	16 RC	549.7	0.320

* The numerical portion of the code was assigned for operator tracking purposes only and has no statistical significance. The remaining code is deciphered as follows:

R = Rubber Plates; P = Photopolymer Plates; B = B Flute; C = C Flute.

TABLE A-2: PHOTOPOLYMER DATA DISPLAYED IN AVERAGE EFFECT ORDER

		* DESIGN MATRIX	RESULT
Run 1 (20PB)	1	111111	591.1
	2		528.5
	3		569.7
	4		576.3
	5		625.8
AVERAGE			578.3
Run 2 (33PB)	1	221112	410.1
	2		470.4
	3		390.8
	4		392.8
	5		436.4
AVERAGE			420.1
Run 3 (34PB)	1	112212	524.6
	2		455.6
	3		492.8
	4		468.4
	5		477.8
AVERAGE			483.8
Run 4 (4PB)	1	222211	471.1
	2		468.7
	3		447.5
	4		480.5
	5		487.9
AVERAGE			471.1
Run 5 (19PC)	1	212122	585.9
	2		600.5
	3		529.3
	4		569.7
	5		594.8
AVERAGE			576.0
Run 6 (35PC)	1	122122	595.0
	2		585.9
	3		680.3
	4		610.6
	5		575.8
AVERAGE			609.5
Run 7 (12PC)	1	211222	606.4
	2		643.3
	3		628.5
	4		554.4
	5		661.5
AVERAGE			618.8
Run 8 (27PC)	1	121222	627.5
	2		551.4
	3		664.0
	4		663.3
	5		672.1
			635.7

* The design matrix for each run corresponds directly to the appropriate treatment combination identified in Table B-3 on page 65.

TABLE A-3: RUBBER DATA DISPLAYED IN AVERAGE EFFECT ORDER

		* DESIGN MATRIX	RESULT			* DESIGN MATRIX	RESULT
Run 1	1	111111	519.7	Run 5	1	212122	564.7
(20RB)	2		512.3	(19RC)	2		637.9
	3		472.4		3		632.7
	4		475.8		4		617.0
	5		427.3		5		513.5
AVERAGE			481.5	AVERAGE			593.2
Run 2	1	221112	487.2	Run 6	1	122122	647.5
(33RB)	2		451.2	(35RC)	2		548.0
	3		469.7		3		644.8
	4		501.2		4		616.2
	5		500.2		5		629.3
AVERAGE			481.9	AVERAGE			617.2
Run 3	1	112212	440.4	Run 7	1	211222	591.6
(34RB)	2		444.0	(12RC)	2		587.2
	3		454.1		3		691.3
	4		463.3		4		589.4
	5		434.9		5		587.6
AVERAGE			447.3	AVERAGE			609.4
Run 4	1	222211	447.7	Run 8	1	121222	640.8
(4RB)	2		503.2	(27RC)	2		588.1
	3		603.7		3		672.6
	4		496.8		4		609.1
	5		469.2		5		601.2
AVERAGE			504.1	AVERAGE			622.4

* The design matrix for each run corresponds directly to the appropriate treatment combination identified in Table B-3 on page 65.

TABLE A-4: COMPRESSION AND DEFLECTION TEST RESULTS

* Control Data

DATE/TIME: 17 Aug/AM CODE: CONTROL B

COMPRESSION TEST RESULTS (DATA)

DEFLECTION	1	2	3	4	5		AVERAGE	PRELOAD	
.1	160.1	140.8	190.4	155.4	154.4	*	160.2	S1	52.7
								S2	50.7
.2	391.1	340.6	422.9	351.4	361.5	*	373.5	S3	51.4
								S4	50.7
								S5	55.1
MAX FORCE:	464.7	475.1	446.0	464.7	521.4	*	474.4	AVG	52.1 *
MAX DEFLEX:	0.266	0.266	0.233	0.266	0.266	*	0.259		

DATE/TIME: 30 Aug/PM CODE: CONTROL C

COMPRESSION TEST RESULTS (DATA)

DEFLECTION	1	2	3	4	5		AVERAGE	PRELOAD	
.1	176.1	177.3	125.8	150.0	177.3	*	161.3	S1	52.2
								S2	52.7
.2	375.3	369.9	322.1	326.3	373.6	*	353.4	S3	50.7
								S4	52.7
.3	641.8	617	564.2	572.6	652.2	*	609.6	S5	54.4
								AVG	52.5 *
MAX FORCE:	675.6	635.2	661.0	666.5	693.8	*	666.4		
MAX DEFLEX:	0.333	0.333	0.333	0.333	0.333	*	0.333		

* The 16" x 12" x 11" control boxes were unprinted containers fabricated at the same time and under the same operating conditions as the test samples.

TABLE A-5: COMPRESSION AND DEFLECTION TEST RESULTS

Photopolymer Plates / B Flute

DATE/TIME: 16 Aug/AM CODE: 20 PB

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	162.8	159.3	176.8	153.4	162.3	*	162.9	S1	50.2
								S2	50.9
.2	399.2	422.4	425.1	402.4	416.5	*	413.1	S3	54.6
								S4	50.4
.3					625.8	*	625.8	S5	50.7
								AVG	51.4 *
MAX FORCE:	591.1	528.5	569.7	576.3	625.8	*	578.3		
MAX DEFLEX:	0.266	0.266	0.266	0.266	0.300	*	0.273		

DATE/TIME: 16 Aug/AM CODE: 33 PB

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	122.6	162.8	144.3	144.5	157.1	*	146.3	S1	50.9
								S2	50.4
.2	266.7	349.7	315.7	307.6	361.8	*	320.3	S3	51.9
								S4	50.9
								S5	48.5
MAX FORCE:	410.1	470.4	390.8	392.8	436.4	*	420.1	AVG	50.5 *
MAX DEFLEX:	0.266	0.266	0.266	0.266	0.233	*	0.259		

DATE/TIME: 15 Aug/AM CODE: 34 PB

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	187.2	177.5	173.4	157.3	142.3	*	167.5	S1	55.9
								S2	50.2
.2	375.6	387.4	372.6	325.1	325.3	*	357.2	S3	56.8
								S4	51.4
								S5	55.4
MAX FORCE:	524.6	455.6	492.8	468.4	477.8	*	483.8	AVG	53.9 *
MAX DEFLEX:	0.266	0.266	0.266	0.266	0.300	*	0.273		

DATE/TIME: 15 Aug/AM CODE: 4 PB

	#1	#2	#3	#4	#5		AVERAGE	PRELOAD		
DEFLECTION										
.1	217.2	128.5	203.2	172.1	142.8	*	172.8	S1	56.1	
								S2	49.5	
.2	435.9	318.9	440.8	351.2	336.4	*	376.6	S3	52.2	
								S4	50.2	
								S5	49.5	
MAX FORCE:	471.1	468.7	447.5	480.5	487.9	*	471.1	AVG	51.5	*
MAX DEFLEX:	0.233	0.266	0.233	0.266	0.266	*	0.253			

DATE/TIME: 16 Aug/AM CODE: 8 PB

	#1	#2	#3	#4	#5		AVERAGE	PRELOAD		
DEFLECTION										
.1	169.9	146.3	168.4	162.5	179.5	*	165.3	S1	52.4	
								S2	49.0	
.2	370.9	322.4	350.9	326.8	362.8	*	346.8	S3	50.7	
								S4	50.4	
.3		518.4				*	518.4	S5	50.4	
								AVE	50.6	*
MAX FORCE:	486.7	518.4	477.5	438.4	510.3	*	486.3			
MAX DEFLEX:	0.266	0.300	0.266	0.266	0.266	*	0.273			

DATE/TIME: 16 Aug/AM CODE: 23 PB

	#1	#2	#3	#4	#5		AVERAGE	PRELOAD		
DEFLECTION										
.1	97.7	104.1	161.8	128.0	156.4	*	129.6	S1	49.2	
								S2	50.2	
.2	240.6	267.4	349.0	296.3	349.5	*	300.6	S3	50.9	
								S4	51.7	
.3	432.5	484.4		470.9		*	462.6	S5	51.7	
								AVG	50.7	*
MAX FORCE:	432.5	484.4	466.0	470.9	412.8	*	453.3			
MAX DEFLEX:	0.300	0.300	0.266	0.300	0.233	*	0.280			

TABLE A-6: COMPRESSION AND DEFLECTION TEST RESULTS

Rubber Plates / B Flute

DATE/TIME: 16 Aug/AM CODE: 20 RB

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	92.3	117.9	100.7	132.7	126.3	*	114.0	S1	48.0
								S2	50.0
.2	260.1	250.9	260.6	289.4	285.4	*	269.3	S3	53.2
								S4	51.4
.3	472.6	458.1	472.4	475.8	427.3	*	461.2	S5	51.4
								AVG	50.8 *
MAX FORCE:	519.7	512.3	472.4	475.8	427.3	*	481.5		
MAX DEFLEX:	0.333	0.333	0.300	0.300	0.300	*	0.313		

DATE/TIME: 16 Aug/AM CODE: 33 RB

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	112.8	117.2	128.0	100.7	103.4	*	112.4	S1	50.0
								S2	48.6
.2	275.8	296.3	318.2	270.2	256.1	*	283.3	S3	50.7
								S4	49.7
.3	487.2		469.7	501.2	455.4	*	478.4	S5	50.7
								AVG	49.9 *
MAX FORCE:	487.2	451.2	469.7	501.2	500.2	*	481.9		
MAX DEFLEX:	0.300	0.266	0.300	0.300	0.333	*	0.300		

DATE/TIME: 16 Aug/AM CODE: 34 RB

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	140.1	179.5	184.9	148.2	149.2	*	160.4	S1	50.2
								S2	51.7
.2	316.5	352.9	388.6	349.2	337.2	*	348.9	S3	50.4
								S4	48.7
								S5	52.2
MAX FORCE:	440.4	444.0	454.1	463.3	434.9	*	447.3	AVG	50.6 *
MAX DEFLEX:	0.266	0.266	0.233	0.266	0.266	*	0.259		

DATE/TIME: 16 Aug/AM CODE: 4 RB

	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
DEFLECTION									
.1	187.9	168.9	174.1	170.4	161.0	*	172.5	S1	52.4
								S2	50.9
.2	420.4	425.3	432.5	400.5	359.8	*	407.7	S3	52.7
								S4	50.0
								S5	52.7
MAX FORCE:	447.7	503.2	603.7	496.8	469.2	*	504.1	AVG	51.7 *
MAX DEFLEX:	0.233	0.233	0.266	0.266	0.266	*	0.253		

DATE/TIME: 16 Aug/AM CODE: 8 RB

	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
DEFLECTION									
.1	125.8	126.1	144.8	164.0	185.9	*	149.3	S1	51.4
								S2	51.4
.2	308.6	326.3	349.0	355.1	426.8	*	353.2	S3	51.7
								S4	52.7
.3	460.3					*	460.3	S5	53.6
								AVG	52.2 *
MAX FORCE:	460.3	485.7	503.7	513.0	507.8	*	494.1		
MAX DEFLEX:	0.300	0.266	0.266	0.266	0.233	*	0.266		

DATE/TIME: 16 Aug/PM CODE: 23 RB

	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
DEFLECTION									
.1	149.5	148.7	150.0	159.6	141.6	*	149.9	S1	50.0
								S2	47.2
.2	312.3	331.7	364.7	370.4	304.1	*	336.6	S3	50.0
								S4	50.9
								S5	50.0
MAX FORCE:	426.8	433.0	434.9	438.1	405.4	*	427.6	AVG	49.6 *
MAX DEFLEX:	0.266	0.266	0.233	0.233	0.266	*	0.253		

TABLE A-7: COMPRESSION AND DEFLECTION TEST RESULTS

Photopolymer Plates / C Flute

DATE/TIME: 17 Aug/AM CODE: 19 PC

	#1	#2	#3	#4	#5	AVERAGE	PRELOAD
DEFLECTION							
.1	144.8	117.2	150.0	141.3	122.6	* 135.2	S1 51.7
							S2 48.5
.2	272.6	269.9	309.6	292.3	256.6	* 280.2	S3 53.2
							S4 52.4
.3	531.2	529.3	569.7	533.2	492.6	* 531.2	S5 51.9
							AVG 51.5 *
MAX FORCE:	600.5	529.3	569.7	594.8	585.9	* 576.0	
MAX DEFLEX:	0.333	0.300	0.300	0.333	0.366	* 0.326	

DATE/TIME: 17 Aug/AM CODE: 35 PC

	#1	#2	#3	#4	#5	AVERAGE	PRELOAD
DEFLECTION							
.1	125.8	162.0	125.6	129.0	143.3	* 137.1	S1 51.4
							S2 52.2
.2	261.0	308.1	271.6	260.1	293.8	* 278.9	S3 50.4
							S4 50.7
.3	528.3	585.9	558.6	512.8	559.6	* 549.0	S5 52.4
							AVG 51.4 *
MAX FORCE:	595.0	585.9	680.3	610.6	575.8	* 609.5	
MAX DEFLEX:	0.333	0.300	0.333	0.333	0.333	* 0.326	

DATE/TIME: 15 Aug/AM CODE: 12 PC

	#1	#2	#3	#4	#5	AVERAGE	PRELOAD
DEFLECTION							
.1	151.4	156.9	145.3	163.3	166.0	* 156.6	S1 53.4
							S2 52.4
.2	315.2	319.2	275.6	316.7	325.8	* 310.5	S3 53.6
							S4 53.6
.3	608.1	599.0	539.6	593.3	582.0	* 584.4	S5 54.9
							AVG 53.6 *
MAX FORCE:	643.3	628.5	554.4	661.5	606.4	* 618.8	
MAX DEFLEX:	0.333	0.333	0.333	0.333	0.333	* 0.333	

DATE/TIME: 17 Aug/AM CODE: 27 PC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE
.1	138.6	134.4	143.6	139.4	138.4	*	138.9
.2	287.9	268.4	284.4	278.8	277.1	*	279.3
.3	541.1	555.1	558.6	550.2	520.4	*	545.1
MAX FORCE:	551.4	664.0	663.3	672.1	627.5	*	635.7
MAX DEFLEX:	0.333	0.333	0.333	0.366	0.333	*	0.340

PRELOAD		
S1	50.0	
S2	52.2	
S3	51.2	
S4	52.4	
S5	50.7	
AVG	51.3	*

DATE/TIME: 15 Aug/AM CODE: 14 PC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE
.1	115.2	96.0	122.6	136.7	113.8	*	116.9
.2	246.5	209.6	251.2	297.5	236.2	*	248.2
.3	485.4	417.2	480.0	575.6	445.0	*	480.6
.4		639.9			652.9	*	646.4
MAX FORCE:	677.1	644.5	630.0	722.6	652.9	*	665.4
MAX DEFLEX:	0.366	0.433	0.366	0.366	0.400	*	0.386

PRELOAD		
S1	51.9	
S2	50.2	
S3	52.2	
S4	51.4	
S5	51.2	
AVG	51.4	*

DATE/TIME: 15 Aug/PM CODE: 16 PC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE
.1	128.8	128.5	153.7	144.5	132.2	*	137.5
.2	267.9	267.0	296.5	292.8	291.6	*	283.2
.3	524.6	514.5	557.6	561.0	568.7	*	545.3
MAX FORCE:	524.6	514.5	617.9	589.1	637.2	*	576.7
MAX DEFLEX:	0.300	0.300	0.333	0.333	0.333	*	0.320

PRELOAD		
S1	50.0	
S2	48.7	
S3	51.7	
S4	50.7	
S5	47.2	
AVG	49.7	*

TABLE A-8: COMPRESSION AND DEFLECTION TEST RESULTS

Rubber Plates / C Flute

DATE/TIME: 15 Aug/PM CODE: 19 RC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	109.6	115.5	124.3	112.3	119.2	*	116.2	S1	48.5
								S2	50.4
.2	236.9	245.0	280.0	252.7	247.0	*	252.3	S3	50.4
								S4	52.9
.3	460.1	488.6	545.5	485.2	474.8	*	490.8	S5	50.9
								AVG	50.6 *
MAX FORCE:	564.7	637.9	632.7	617.0	513.5	*	593.2		
MAX DEFLEX:	0.366	0.366	0.333	0.366	0.333	*	0.353		

DATE/TIME: 17 Aug/AM CODE: 35 RC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	133.7	154.4	151.2	150.5	147.3	*	147.4	S1	50.4
								S2	53.2
.2	282.5	289.9	330.3	330.3	327.1	*	312.0	S3	50.7
								S4	50.7
.3	550.5	548.0	612.8	560.1	629.3	*	580.1	S5	50.2
								AVG	51.0 *
MAX FORCE:	647.5	548.0	644.8	616.2	629.3	*	617.2		
MAX DEFLEX:	0.333	0.300	0.333	0.333	0.300	*	0.320		

DATE/TIME: 17 Aug/AM CODE: 12 RC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	151.9	159.1	144.3	139.9	131.2	*	145.3	S1	51.7
								S2	54.1
.2	306.9	336.9	291.3	293.1	267.4	*	299.1	S3	51.9
								S4	50.2
.3	591.6	587.2	590.8	577.3	511.0	*	571.6	S5	49.7
								AVG	51.5 *
MAX FORCE:	591.6	587.2	691.3	589.4	587.6	*	609.4		
MAX DEFLEX:	0.300	0.300	0.333	0.333	0.333	*	0.320		

DATE/TIME: 15 Aug/AM CODE: 27 RC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	135.9	129.5	137.6	142.8	118.7	*	132.9	S1	53.6
								S2	56.4
.2	307.3	265.2	266.2	295.8	266.5	*	280.2	S3	51.4
								S4	54.1
.3	584.9	527.5	551.9	591.6	512.5	*	553.7	S5	52.7
								AVG	53.6 *
MAX FORCE:	640.8	588.1	672.6	609.1	601.2	*	622.4		
MAX DEFLEX:	0.333	0.333	0.333	0.333	0.333	*	0.333		

DATE/TIME: 16 Aug/PM CODE: 14 RC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	122.6	147.3	149.2	148.2	151.9	*	143.8	S1	49.5
								S2	50.0
.2	271.6	317.9	331.0	315.7	325.8	*	312.4	S3	52.4
								S4	52.2
.3	516.0	558.6	542.1	569.9	560.1	*	549.3	S5	50.2
								AVG	50.9 *
MAX FORCE:	572.4	558.6	542.1	641.8	562.5	*	575.5		
MAX DEFLEX:	0.333	0.300	0.300	0.333	0.333	*	0.320		

DATE/TIME: 15 Aug/PM CODE: 16 RC

DEFLECTION	#1	#2	#3	#4	#5		AVERAGE	PRELOAD	
.1	122.4	136.2	117.2	134.0	121.1	*	126.2	S1	48.2
								S2	48.0
.2	255.9	295.0	251.2	266.2	250.2	*	263.7	S3	51.2
								S4	50.4
.3	540.8	478.5	480.0	495.0	513.0	*	501.5	S5	49.7
								AVG	49.5 *
MAX FORCE:	650.5	478.5	480.0	550.9	588.4	*	549.7		
MAX DEFLEX:	0.333	0.300	0.300	0.333	0.333	*	0.320		

TABLE A-9: PHOTOPOLYMER - CALCULATION OF AVERAGE RESPONSES

Level 1 (Center)

A	578.3
	483.8
	609.5
	635.7
$\bar{x}$	576.8

Level 2 (Corners)

B	420.1
	471.1
	576.0
	618.8
$\bar{x}$	521.5

Level 1 (2-Panel)

A	578.3
	483.8
	576.0
	618.8
$\bar{x}$	564.2

Level 2 (4-Panel)

B	420.1
	471.1
	609.5
	635.7
$\bar{x}$	534.1

Level 1 (15%)

A	578.3
	420.1
	618.8
	635.7
$\bar{x}$	563.2

Level 2 (30%)

B	483.8
	471.1
	576.0
	609.5
$\bar{x}$	535.1

Level 1 (1-Color)

A	578.3
	420.1
	576.0
	609.5
$\bar{x}$	546.0

Level 2 (2-Color)

B	483.8
	471.1
	618.8
	635.7
$\bar{x}$	552.4

Level 1 (B Flute)

A	578.3
	420.1
	483.8
	471.1
$\bar{x}$	488.3

Level 2 (C Flute)

B	576.0
	609.5
	618.8
	635.7
$\bar{x}$	610.0

TABLE A-10: RUBBER - CALCULATION OF AVERAGE RESPONSES

	Level 1 (Center)		Level 2 (Corner)
A	* 516.0	A	* 469.4
	* 463.3		* 458.5
	617.2		593.2
	622.4		609.4
$\bar{x}$	554.7	$\bar{x}$	532.6

	Level 1 (2-Panel)		Level 2 (4-Panel)
A	* 516.0	A	* 469.4
	* 463.3		* 458.5
	593.2		617.2
	609.4		622.4
$\bar{x}$	545.5	$\bar{x}$	541.9

	Level 1 (15%)		Level 2 (30%)
A	* 516.0	A	* 463.3
	* 469.4		* 458.5
	609.4		593.2
	622.4		617.2
$\bar{x}$	554.3	$\bar{x}$	533.0

	Level 1 (1-Color)		Level 2 (2-Color)
A	* 516.0	A	* 463.3
	* 469.4		* 458.5
	593.2		609.4
	617.2		622.4
$\bar{x}$	549.0	$\bar{x}$	538.4

	Level 1 (B Flute)		Level 2 (C Flute)
A	* 516.0	A	593.2
	* 469.4		608.9
	* 463.3		617.2
	* 458.5		622.4
$\bar{x}$	476.8	$\bar{x}$	610.4

* Averages calculated with less than 4 replicates.

TABLE A-11: Analysis of Variance (ANOVA) - Photopolymer Plates

SOURCE	DF	MEAN SQUARE	F	95% CONFIDENCE
Location	1	30,819	15.58	Significant **
Panel	1	9,214	4.66	Significant
Amount	1	7,765	3.93	Significant *
Color	1	435	0.22	Not Significant
Flute	1	148,486	75.08	Significant **
Residual	34	1978		
Total	39			

* Amount was significant at 90% confidence

** Location and Flute were significant at 99% confidence

TABLE A-12: Analysis of Variance (ANOVA) - Rubber Plates

SOURCE	DF	MEAN SQUARE	F	95% CONFIDENCE
Location	1	3,423	2.30	Significant *
Panel	1	238	0.16	Not Significant
Amount	1	1,818	1.22	Not Significant
Color	1	310	0.21	Not Significant
Flute	1	90,694	60.89	Significant **
Residual	34	1489		
Total	39			

* Location was significant at 75% confidence

** Flute was significant at 99% confidence

APPENDIX B

TABLE B-1: Full-Factorial Design (Montgomery, 1984)

TREATMENT COMBINATION	LOCATION	PANEL	AMOUNT	COLUMN	FLUTE	SHAPE
(1)	1	1	1	1	1	1
a	2	1	1	1	1	1
b	1	2	1	1	1	1
ab	2	2	1	1	1	1
c	1	1	2	1	1	1
ac	2	1	2	1	1	1
bc	1	2	2	1	1	1
abc	2	2	2	1	1	1
d	1	1	1	2	1	1
ad	2	1	1	2	1	1
bd	1	2	1	2	1	1
abd	2	2	1	2	1	1
cd	1	1	2	2	1	1
acd	2	1	2	2	1	1
bcd	1	2	2	2	1	1
abcd	2	2	2	2	1	1
e	1	1	1	1	2	1
ae	2	1	1	1	2	1
be	1	2	1	1	2	1
abe	2	2	1	1	2	1
ce	1	1	2	1	2	1
ace	2	1	2	1	2	1
bce	1	2	2	1	2	1
abce	2	2	2	1	2	1
de	1	1	1	2	2	1
ade	2	1	1	2	2	1
bde	1	2	1	2	2	1
abde	2	2	1	2	2	1
cde	1	1	2	2	2	1
acde	2	1	2	2	2	1

(TABLE B-1, Continued)

TREATMENT COMBINATION	LOCATION	PANEL	AMOUNT	COLUMN	FLUTE	SHAPE
abcde	2	2	2	2	2	1
f	1	1	1	1	1	2
af	2	1	1	1	1	2
bf	1	2	1	1	1	2
abf	2	2	1	1	1	2
cf	1	1	2	1	1	2
acf	2	1	2	1	1	2
bcf	1	2	2	1	1	2
abcf	2	2	2	1	1	2
df	1	1	1	2	1	2
adf	2	1	1	2	1	2
bdf	1	2	1	2	1	2
abdf	2	2	1	2	1	2
cdf	1	1	2	2	1	2
acdf	2	1	2	2	1	2
bcdf	1	2	2	2	1	2
abcdf	2	2	2	2	1	2
ef	1	1	1	1	2	2
aef	2	1	1	1	2	2
bef	1	2	1	1	2	2
abef	2	2	1	1	2	2
cef	1	1	2	1	2	2
acef	2	1	2	1	2	2
bcef	1	2	2	1	2	2
abcef	2	2	2	1	2	2
def	1	1	1	2	2	2
adef	2	1	1	2	2	2
bdef	1	2	1	2	2	2
abdef	2	2	1	2	2	2
cdef	1	1	2	2	2	2
acdef	2	1	2	2	2	2
bcdef	1	2	2	2	2	2
abcdef	2	2	2	2	2	2

TABLE B-2: Half-Fractional Factorial Design (Montgomery, 1984)

TREATMENT COMBINATION	Location	Panel	Amount	Colors	Flute	Shape
(1)	1	1	1	1	1	1
a	2	1	1	1	1	2
b	1	2	1	1	1	2
ab	2	2	1	1	1	1
c	1	1	2	1	1	2
ac	2	1	2	1	1	1
bc	1	2	2	1	1	1
abc	2	2	2	1	1	2
d	1	1	1	2	1	2
ad	2	1	1	2	1	1
bd	1	2	1	2	1	1
abd	2	2	1	2	1	2
cd	1	1	2	2	1	1
acd	2	1	2	2	1	2
bcd	1	2	2	2	1	2
abcd	2	2	2	2	1	1
e	1	1	1	1	2	2
ae	2	1	1	1	2	1
be	1	2	1	1	2	1
abe	2	2	1	1	2	2
ce	1	1	2	1	2	1
ace	2	1	2	1	2	2
bce	1	1	2	1	2	2
abce	2	2	2	1	2	1
de	1	1	1	2	2	1
ade	2	1	1	2	2	2
bde	1	2	1	2	2	2
abde	2	2	1	2	2	1
cde	1	1	2	2	2	2
acde	2	1	2	2	2	1
bcde	1	2	2	2	2	1
abcde	2	2	2	2	2	2

TABLE B-3: L8 Design for Six Factors, Two Levels (Taguchi, 1989)

*TREATMENT COMBINATION	COLUMN NUMBER 1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

* The definition of terms for treatment combinations (1, 2) are referenced in Table B-5 on page 66. The factors assigned to column numbers are referenced on page 28 (the factors are listed in reverse order to those on page 66).

TABLE B-4: Compression Test Sequence

Day 1 - 25RB, 27RB, 1PB, 10PB, 22RB, 34PB, 4PB, 29RB, 3PB, 12PC, 18RC, 14PC, 29PB, 11PB, 22PB, 9RC, 16RC, 16PC, 17PC, 19RC, 17RC, 36RC, 21PC, 5PC, CONTROL C, 11RB, 26RB

DAY 2 - 8PB, 33PB, 5RC, 3RB, CONTROL C, 1RB, 6PB, 34RB, 10RB, 20PB, 28PB, 31PB, 4RB, 33RB, 26PB, 23PB, 15RB, 15PB, 6RB, 8RB, 20RB, 24PC, 31RB, 23RB, 28RB, 24RC, 18PC, 30RC, 32PC, 32RC, 21RC, 14RC, 7RC

DAY 3 - 27PC, 9PC, 2RC, 30PC, CONTROL B, 25PB, 13RC, 36PC, 2PC, 35PC, 7PC, 19PC, 12RC, 13PC, 35RC, CONTROL B

TABLE B-5: Design Factors

FACTOR 1 - Location of Print on Panels:

1 = Center panel	2 = One inch to corner

FACTOR 2 - Panels Printed:

1 = Two major	2 = All four panels

FACTOR 3 - Amount of Print Coverage:

1 = 15%	2 = 30%

FACTOR 4 - Number of Colors:

1 = One Color	2 = Two Colors

FACTOR 5 - Flute:

1 = B Flute	2 = C Flute

FACTOR 6 - Print Shape:

1 = Square	2 = Rectangle

TABLE B-6: Taguchi L4 and L8 Orthogonal Arrays (Taguchi, 1989)

L4 Orthogonal Array:

	Column #		
Trial #	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

L8 Orthogonal Array:

	Column #						
Trial #	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

TABLE B-7: Taguchi L12 Orthogonal Array (Taguchi, 1989)

L12 Orthogonal Array:

Trial #	Column #										
	1	2	3	4	5	6	7	8	9	10	11
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	2	2	2	2	2
3	1	1	2	2	2	1	1	1	2	2	2
4	1	2	1	2	2	1	2	2	1	1	2
5	1	2	2	1	2	2	1	2	1	2	1
6	1	2	2	2	1	2	2	1	2	1	1
7	2	1	2	2	1	1	2	2	1	2	1
8	2	1	2	1	2	2	2	1	1	1	2
9	2	1	1	2	2	2	1	2	2	1	1
10	2	2	2	1	1	1	1	2	2	1	2
11	2	2	1	2	1	2	1	1	1	2	2
12	2	2	1	1	2	1	2	1	2	2	1

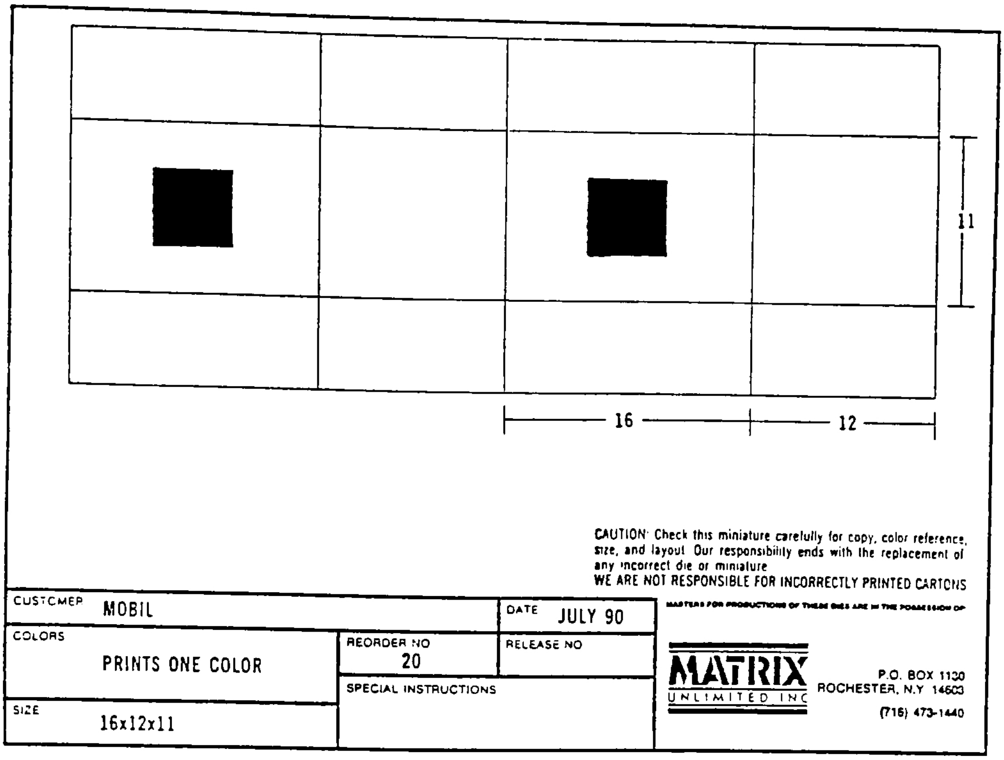
TABLE B-8: Taguchi L16 Orthogonal Array (Taguchi, 1989)

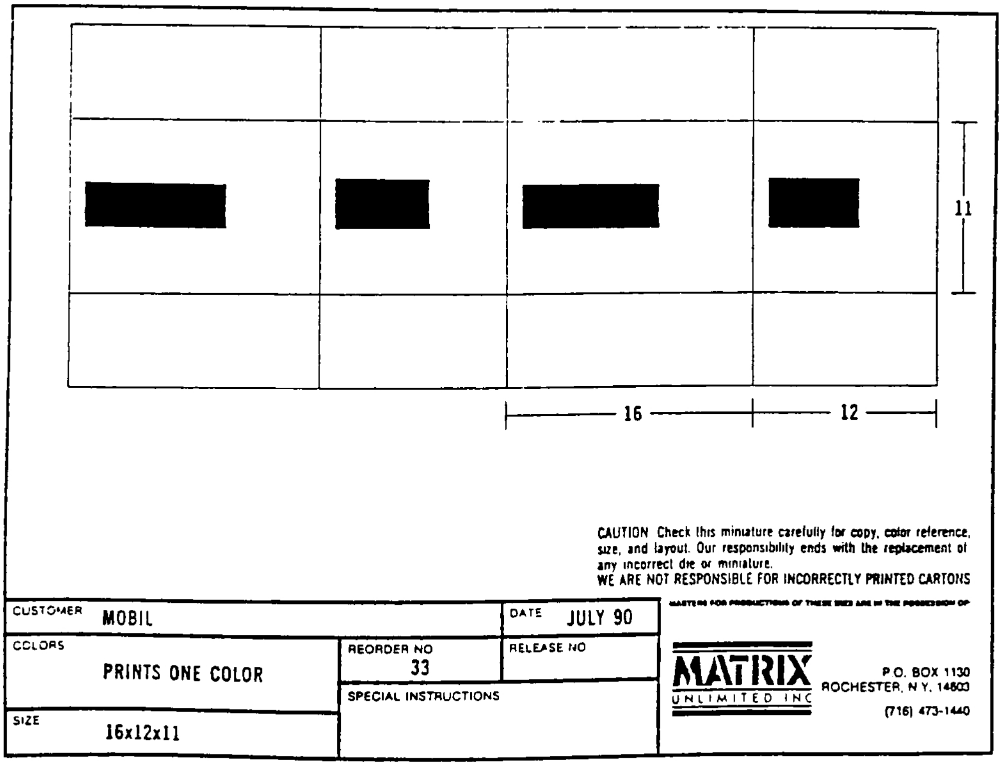
L16 Orthogonal Array:

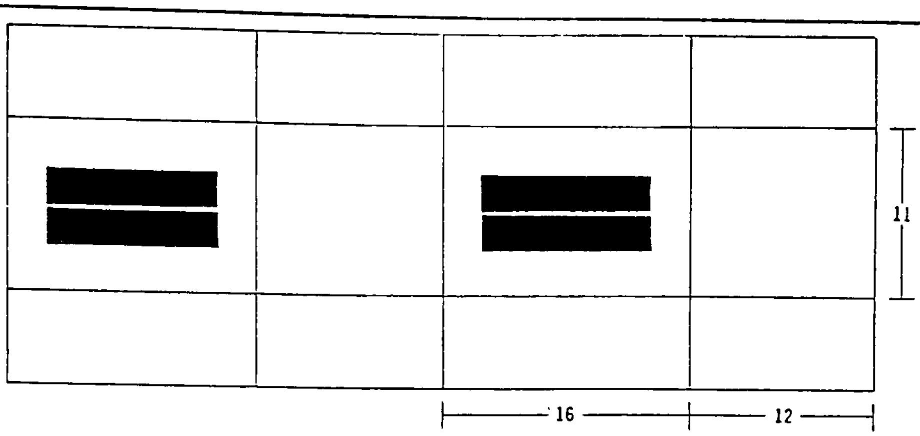
	Column #														
Trial #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

APPENDIX C

TABLE C-1: RESEARCH PRINTING PLATES

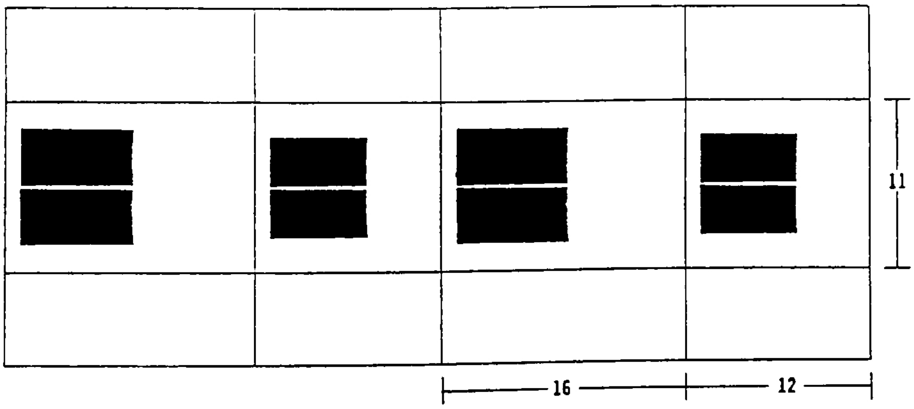






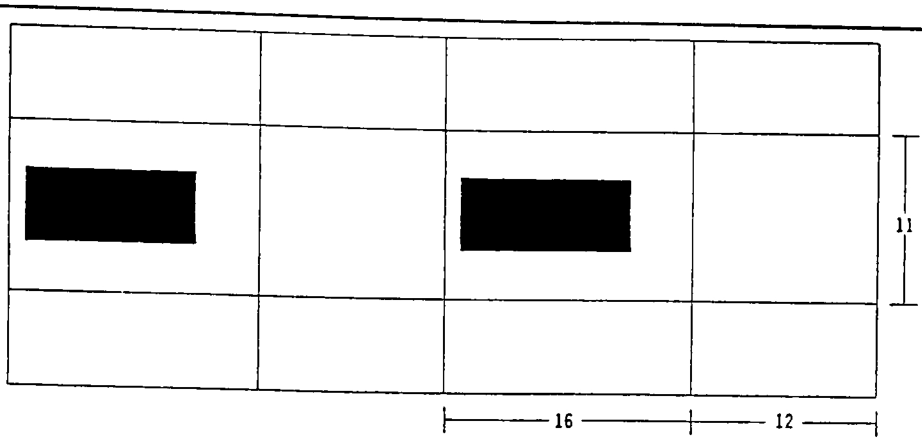
CAUTION Check this miniature carefully for copy, color reference, size, and layout Our responsibility ends with the replacement of any incorrect die or miniature
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90	
COLORS PRINTS TWO COLORS	REORDER NO 34	RELEASE NO	MATRIX UNLIMITED INC P.O BOX 1130 ROCHESTER, N Y 14603 (716) 473-1440
	SPECIAL INSTRUCTIONS		
SIZE 16x12x11			



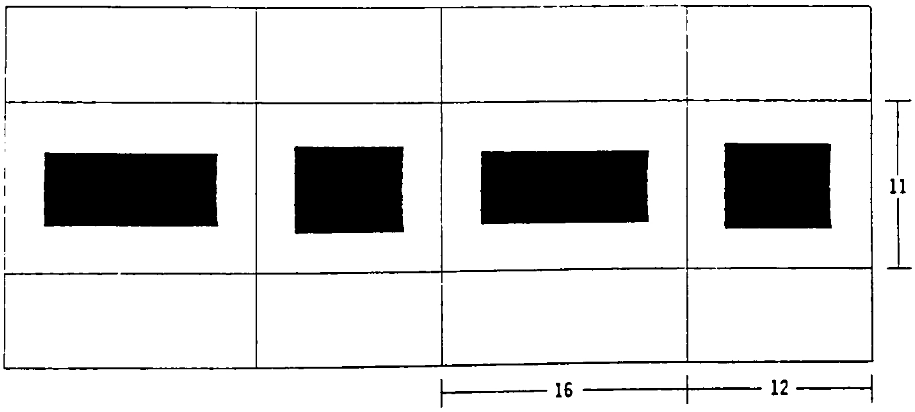
CAUTION: Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90	
COLORS. PRINTS TWO COLORS	REORDER NO. 4	RELEASE NO.	MATRIX UNLIMITED INC P.O. BOX 1130 ROCHESTER, N.Y. 14603 (716) 473-1440
	SPECIAL INSTRUCTIONS.		
SIZE 16x12x11			



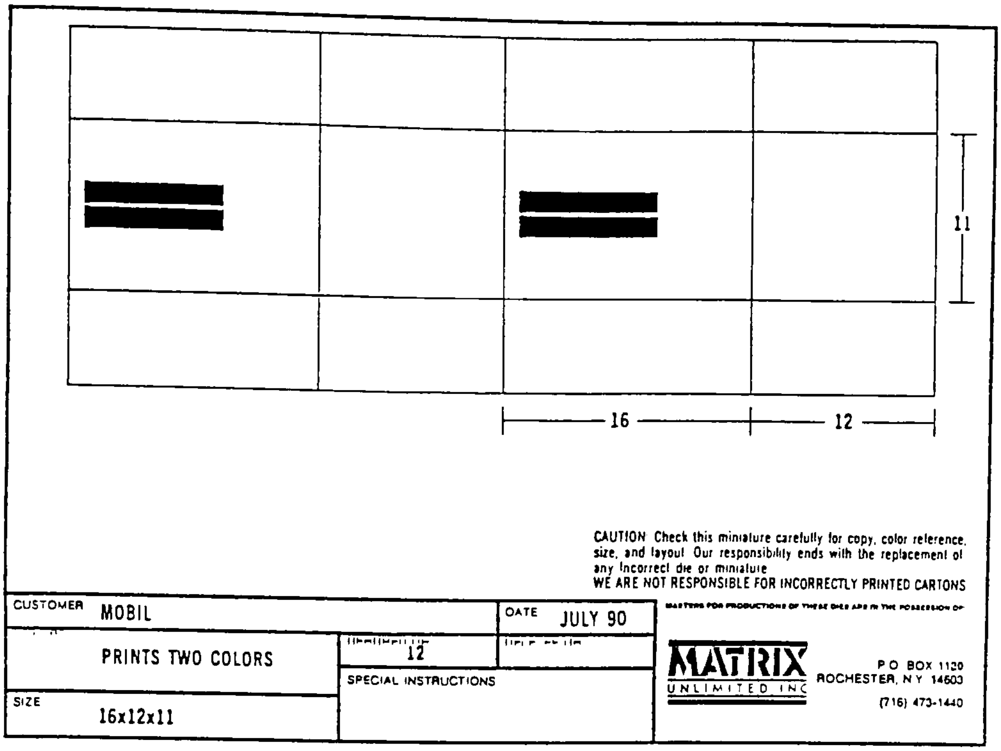
CAUTION Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90	MASTERS FOR PRODUCTIONS OF THESE DIES ARE IN THE POSSESSION OF
COLORS PRINTS ONE COLOR	REORDER NO 19	RELEASE NO	MATRIX UNLIMITED INC P.O BOX 1130 ROCHESTER, N.Y. 14603 (716) 473-1440
	SPECIAL INSTRUCTIONS		
SIZE 16x12x11			



CAUTION: Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90	MASTERS FOR PRODUCTIONS OF THESE DIES ARE IN THE POSSESSION OF
COLORS PRINTS ONE COLOR	REORDER NO. 35	RELEASE NO	MATRIX UNLIMITED INC P.O BOX 1130 ROCHESTER, N.Y. 14603 (716) 473-1440
	SPECIAL INSTRUCTIONS		
SIZE 16x12x11			


11
16
12
CAUTION Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS
CUSTOMER MOBIL
DATE JULY 90
PRINTS TWO COLORS
12
SPECIAL INSTRUCTIONS
SIZE 16x12x11
MATRIX UNLIMITED INC
P O BOX 1120 ROCHESTER, N Y 14603
(716) 473-1440

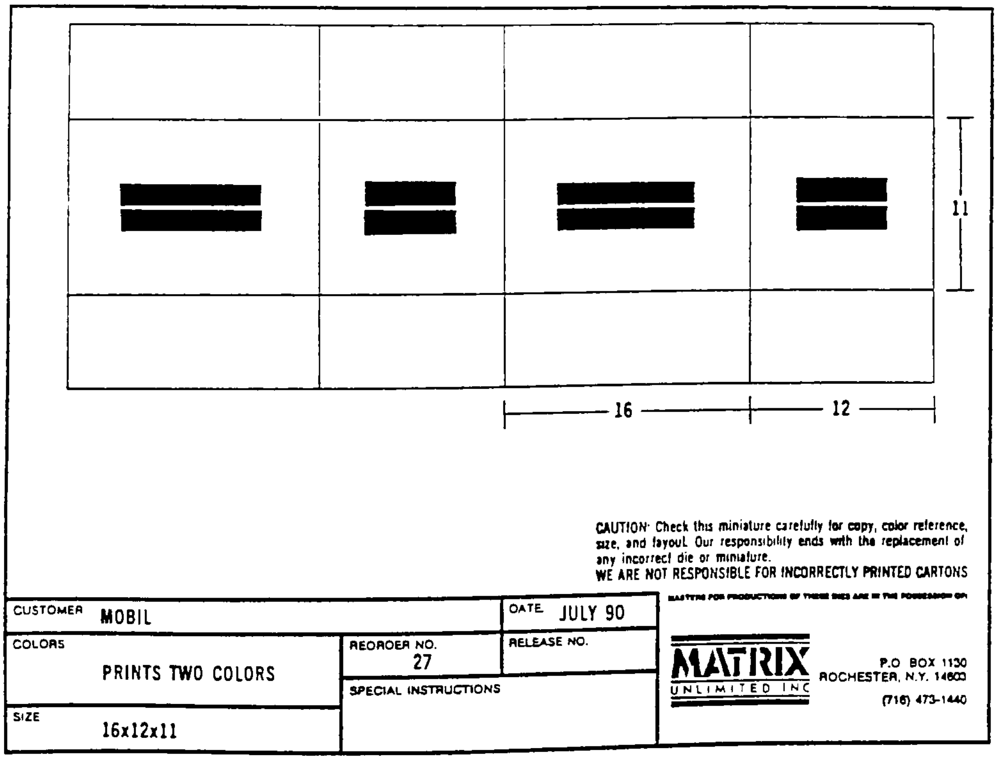
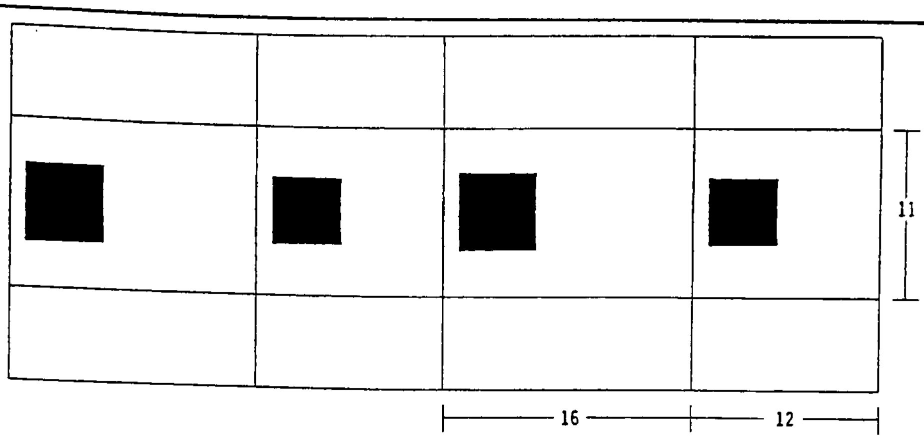

11
16
12
CAUTION: Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS
CUSTOMER MOBIL
DATE JULY 90
COLORS
PRINTS TWO COLORS
REORDER NO. 27
RELEASE NO.
SPECIAL INSTRUCTIONS
SIZE 16x12x11
MATRIX UNLIMITED INC
P.O BOX 1130 ROCHESTER, N.Y. 14603
(716) 473-1440

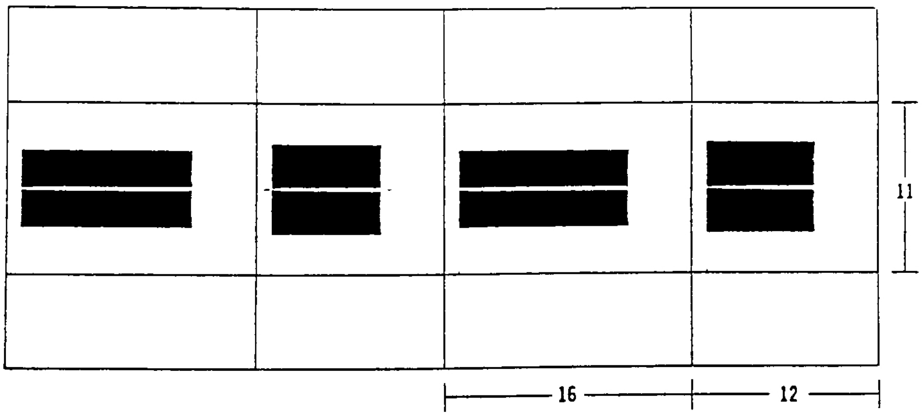
TABLE C-2: VERIFICATION PRINTING PLATES



CAUTION: Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90	
COLORS PRINTS ONE COLOR	REORDER NO. 8	RELEASE NO	
	SPECIAL INSTRUCTIONS.		
SIZE 16x12x11			

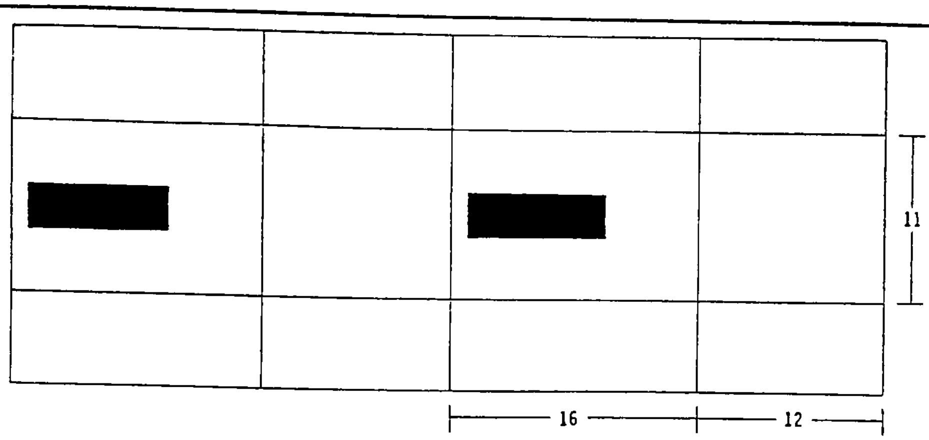
MATRIX UNLIMITED INC
P.O. BOX 1130
ROCHESTER, N.Y. 14603
(716) 473-1440



CAUTION: Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90	
COLORS. PRINTS TWO COLORS	REORDER NO 14	RELEASE NO	
	SPECIAL INSTRUCTIONS.		
SIZE 16x12x11			

MATRIX UNLIMITED INC
P O BOX 1130
ROCHESTER N Y 14603
(716) 473-1440



CAUTION Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90
COLORS PRINTS ONE COLOR	REORDER NO 23	RELEASE NO
	SPECIAL INSTRUCTIONS	
SIZE 16x12x11		

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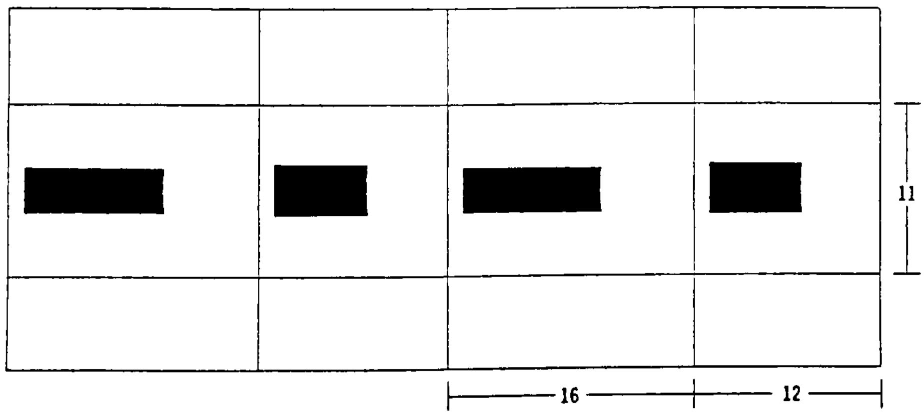

CAUTION Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

CUSTOMER MOBIL		DATE JULY 90
COLORS. PRINTS ONE COLOR	REORDER NO. 16	RELEASE NO
	SPECIAL INSTRUCTIONS	
SIZE 16x12x11		

MASTERS FOR PRODUCTIONS OF THESE DIES ARE IN THE POSSESSION OF

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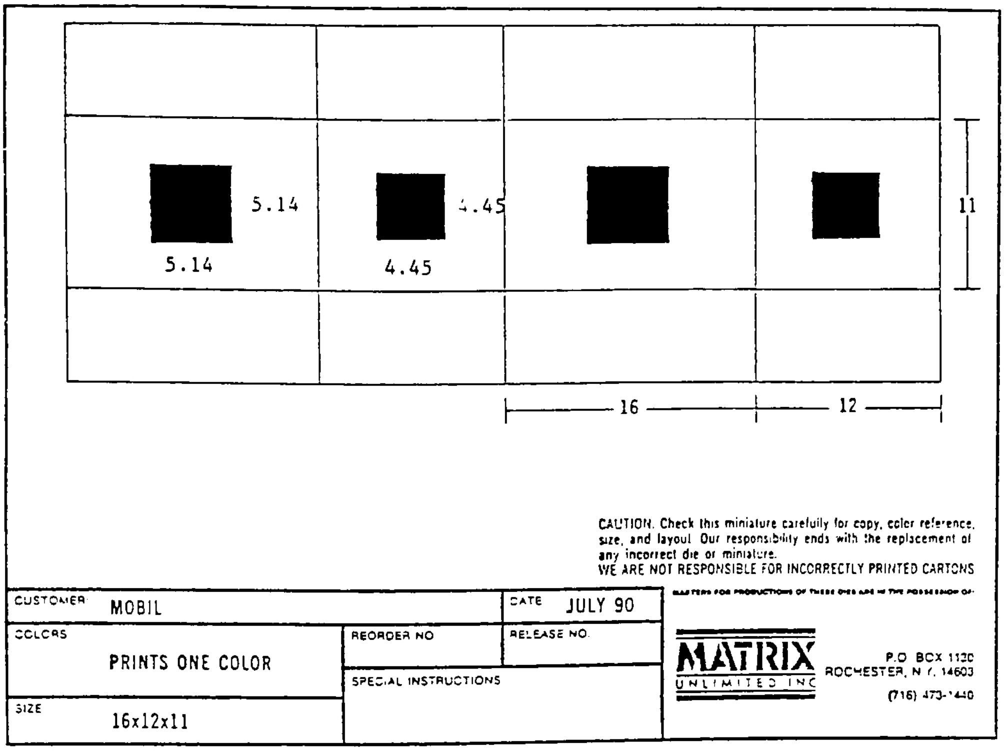
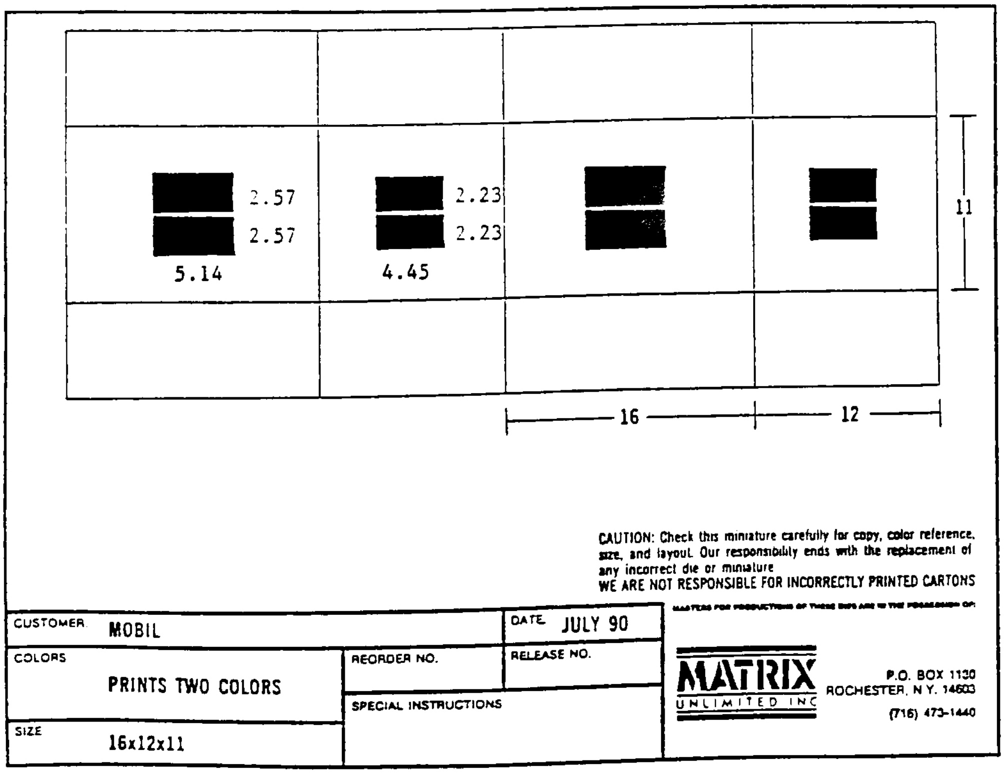
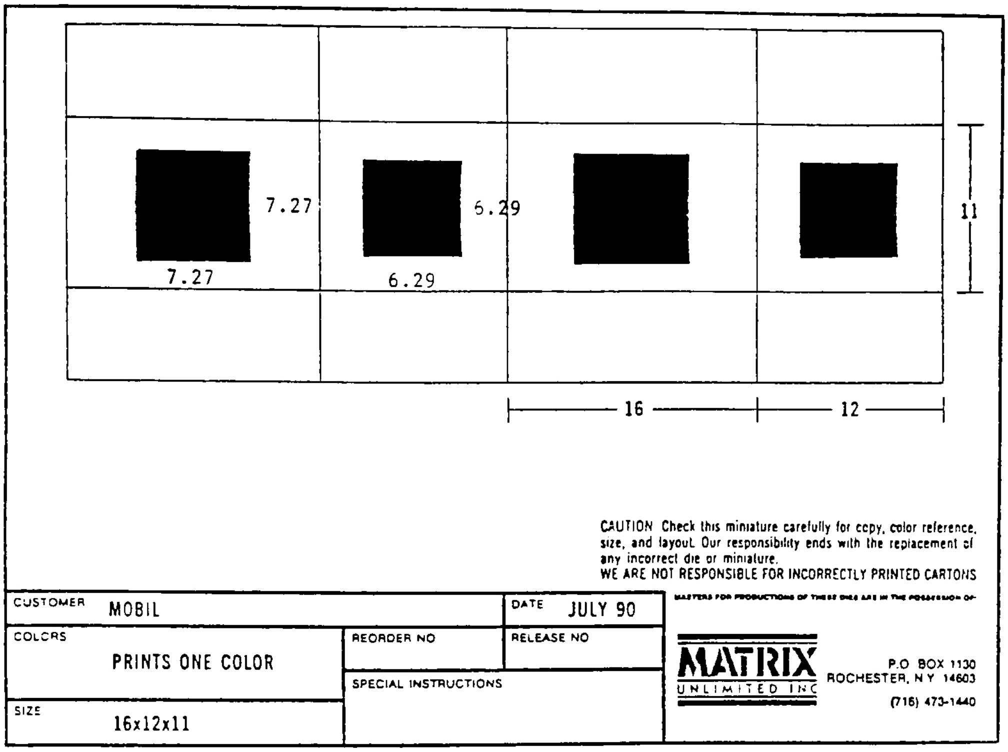
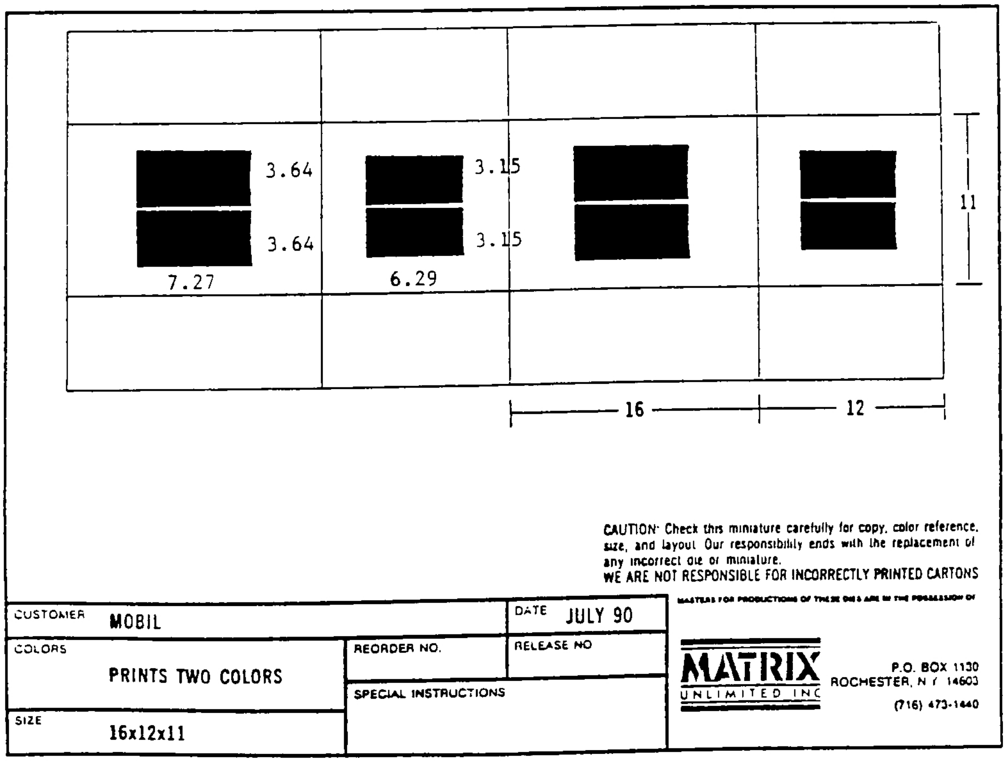
(716) 473-1440

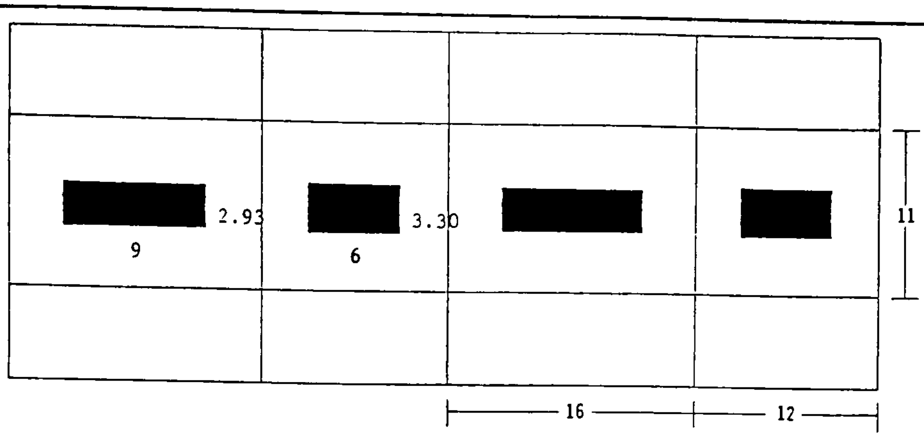
TABLE C-3: PRINTING PLATE DIMENSIONS






7.27
7.27
6.29
6.29
11
16
12
CAUTION Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS
CUSTOMER MOBIL
DATE JULY 90
COLORS PRINTS ONE COLOR
REORDER NO
RELEASE NO
SPECIAL INSTRUCTIONS
SIZE 16x12x11
MATRIX UNLIMITED INC
P.O BOX 1130
ROCHESTER, N Y 14603
(716) 473-1440


3.64
3.64
7.27
3.15
3.15
6.29
11
16
12
CAUTION: Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS
CUSTOMER MOBIL
DATE JULY 90
COLORS PRINTS TWO COLORS
REORDER NO.
RELEASE NO
SPECIAL INSTRUCTIONS
SIZE 16x12x11
MATRIX UNLIMITED INC
P.O. BOX 1130
ROCHESTER, N Y 14603
(716) 473-1440

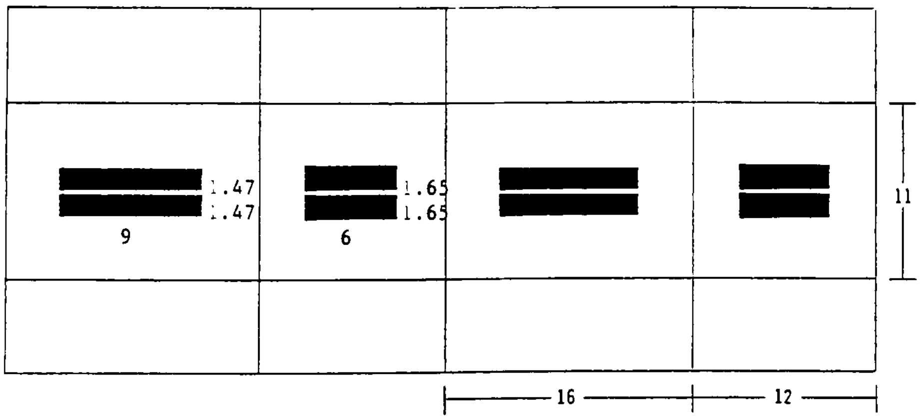


CAUTION. Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

MASTERS FOR PRODUCTIONS OF THESE DIES ARE IN THE POSSESSION OF

CUSTOMER MOBIL		DATE JULY 90
COLORS PRINTS ONE COLOR	REORDER NO	RELEASE NO
	SPECIAL INSTRUCTIONS	
SIZE 16x12x11		

MATRIX UNLIMITED INC
P O BOX 1130
ROCHESTER, N Y 14603
(716) 473-1440

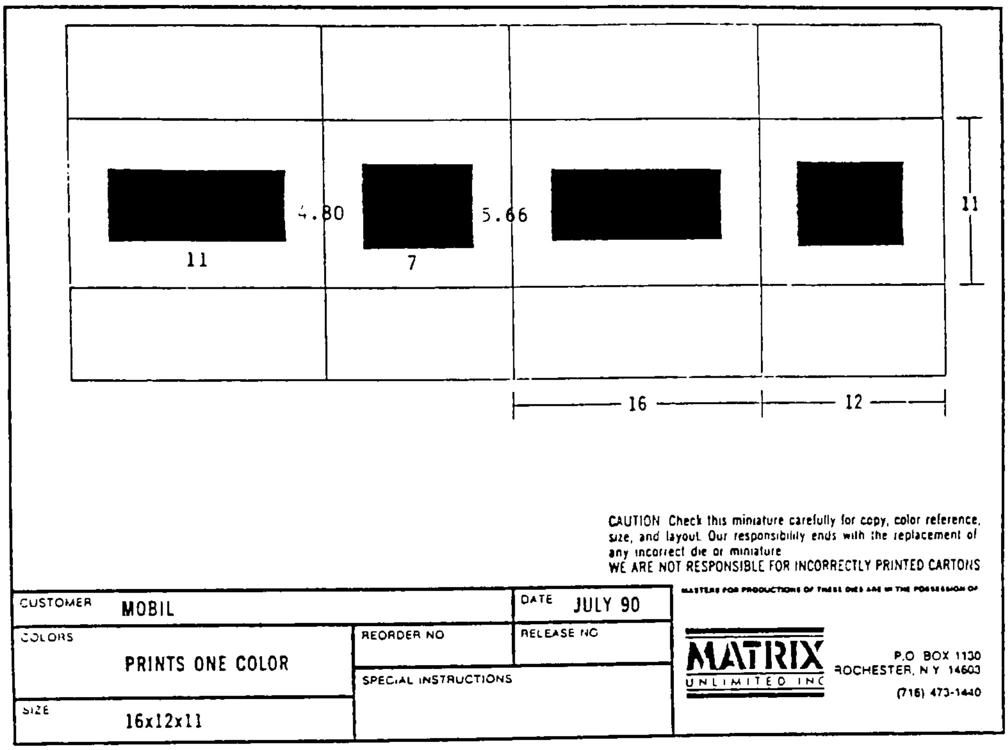


CAUTION Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS

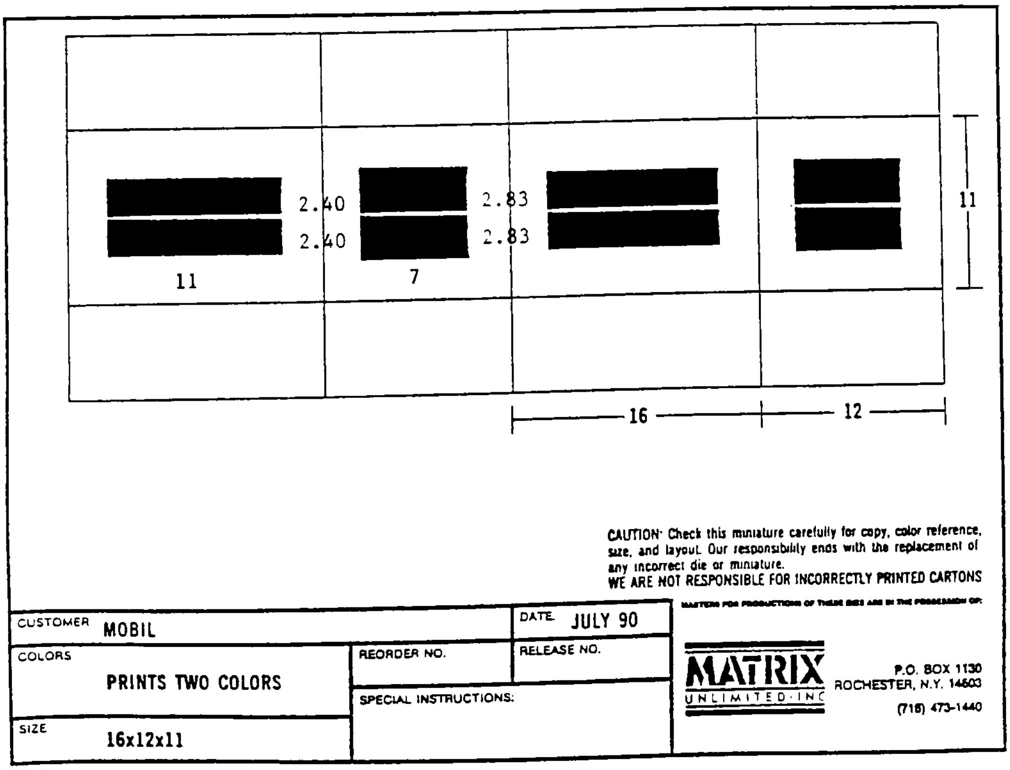
MASTERS FOR PRODUCTIONS OF THESE DIES ARE IN THE POSSESSION OF

CUSTOMER MOBIL		DATE. JULY 90
COLORS PRINTS TWO COLORS	REORDER NO.	RELEASE NO
	SPECIAL INSTRUCTIONS	
SIZE 16x12x11		

MATRIX UNLIMITED INC
P.O. BOX 1130
ROCHESTER, N.Y. 14603
(716) 473-1440



4.80
5.66
11
7
11
16
12
CAUTION Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS
CUSTOMER MOBIL
DATE JULY 90
COLORS PRINTS ONE COLOR
REORDER NO
RELEASE NO
SPECIAL INSTRUCTIONS
SIZE 16x12x11
MATRIX UNLIMITED INC
P.O BOX 1130
ROCHESTER, N Y 14603
(716) 473-1440



2.40
2.40
2.83
2.83
11
7
11
16
12
CAUTION: Check this miniature carefully for copy, color reference, size, and layout. Our responsibility ends with the replacement of any incorrect die or miniature.
WE ARE NOT RESPONSIBLE FOR INCORRECTLY PRINTED CARTONS
CUSTOMER MOBIL
DATE JULY 90
COLORS PRINTS TWO COLORS
REORDER NO.
RELEASE NO.
SPECIAL INSTRUCTIONS:
SIZE 16x12x11
MATRIX UNLIMITED INC
P.O. BOX 1130
ROCHESTER, N.Y. 14603
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8.0 LIST OF REFERENCES

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